SURE Project

August 30, 2022

Objective

Predict and project spatially the result from the models.

```
## Script by Anita Giraldo, 4 May 2022
## Last modified by Anita Giraldo, 4 May 2022

# Clear environment ----
rm(list=ls())

# directories ----
m.dir <- here()
d.dir <- here('data')
# k.dir <- here('outputs_nc_rcca')
# o.dir <- paste(k.dir, "gam_V5", sep ='/') # kelp model results
# u.dir <- paste(k.dir, "gam_urchins3", sep ='/') # urchin model results
# rcca.dir <- "G:/Shared drives/California Kelp Restoration Project - Seagrant/R_Projects/North_Coast_w
# dd.dir <- "G:/Shared drives/California Kelp Restoration Project - Seagrant/R_Projects/Extract_env_dat

## Load info on years RCCA ----
years <- read.csv(paste(d.dir, "RCCA_North_Coast_sites.csv", sep ='/')) %>%
  glimpse() # Rows: 25
```

```
## Rows: 25
## Columns: 7
## $ site_name        <chr> "Caspar", "Caspar North", "Dark Gulch", "Flat Iron Ro~
## $ total.years      <int> 10, 8, 1, 2, 15, 8, 16, 4, 4, 13, 3, 14, 6, 4, 7, 8, ~
## $ pre.mhw.years    <int> 2, NA, NA, NA, 7, NA, 8, NA, NA, 6, NA, 6, NA, NA, 3,~
## $ during.mhw.years <int> 3, 3, NA, NA, 3, 3, 3, 1, NA, 3, NA, 3, 2, NA, 1, 1, ~
## $ post.mhw.years   <int> 5, 5, 1, 3, 5, 5, 5, 3, 4, 4, 3, 5, 4, 4, 3, 4, 5, 3,~
## $ longitude        <dbl> -123.8220, -123.8213, -123.7762, -124.1578, -123.2450~
## $ latitude         <dbl> 39.36173, 39.36443, 39.24030, 41.05942, 38.51060, 39.~
```

```
# get the sites from with preMHW data ----
# 3 or more pre MHW surveys
ncsites <- years %>%
  mutate_at(vars(site_name), list(as.factor)) %>%
  # get only sites with PRE MHW data
  dplyr::filter(pre.mhw.years > 2) %>%
  droplevels() %>%
  glimpse() # Rows: 10
```

```
## Rows: 10
```

```
## Columns: 7
## $ site_name        <fct> Fort Ross, Gerstle Cove, Mendocino Headlands, Ocean C~
## $ total.years      <int> 15, 16, 13, 14, 7, 8, 12, 15, 3, 15
## $ pre.mhw.years    <int> 7, 8, 6, 6, 3, 3, 6, 7, 3, 7
## $ during.mhw.years <int> 3, 3, 3, 3, 1, 1, 1, 3, NA, 3
## $ post.mhw.years   <int> 5, 5, 4, 5, 3, 4, 5, 5, NA, 5
## $ longitude        <dbl> -123.2450, -123.3300, -123.8110, -123.3057, -123.7410~
## $ latitude         <dbl> 38.51060, 38.56646, 39.30528, 38.55512, 38.94480, 38.~
```

1. Load RCCA data

```
df <- read.csv(paste(d.dir, "RCCA_kelp_inverts_NC_depth-zones_wave_clim_temp_nit_subs_orbvel_npp.csv", s
  mutate_at(vars(site_name, month, year, transect, zone), list(as.factor)) %>%
  mutate(zone_new = case_when(
    transect == '1' ~ 'OUTER',
    transect == '2' ~ 'OUTER',
    transect == '3' ~ 'OUTER',
    transect == '4' ~ 'INNER',
    transect == '5' ~ 'INNER',
    transect == '6' ~ 'INNER')) %>%
  dplyr::select(-zone) %>%
  rename(zone = zone_new) %>%
  mutate_at(vars(zone), list(as.factor)) %>%
  relocate(zone, .after = transect) %>%
  glimpse() # Rows: 1,154
```

```
## Rows: 1,154
## Columns: 152
## $ site_name                    <fct> Caspar, Caspar, Caspar, Caspar, ~
## $ month                        <fct> 6, 6, 6, 6, 6, 6, 8, 8, 8, 8, 8,~
## $ year                         <fct> 2018, 2018, 2018, 2018, 2018, 20~
## $ transect                     <fct> 1, 2, 3, 4, 5, 6, 1, 2, 3, 4, 5,~
## $ zone                         <fct> OUTER, OUTER, OUTER, INNER, INNE~
## $ latitude                     <dbl> 39.36173, 39.36173, 39.36173, 39~
## $ longitude                    <dbl> -123.822, -123.822, -123.822, -1~
## $ den_STRPURAD                 <dbl> 37.0000, 184.6154, 52.0000, 22.0~
## $ den_HALRUF                   <dbl> 12, 3, 0, 0, 2, 3, 16, 19, 27, 1~
## $ den_MESFRAAD                 <dbl> 102.00000, 27.00000, 193.33333, ~
## $ den_PYCHEL                   <int> 0, 0, 0, 0, 0, 0, 1, 0, 4, 1, 0,~
## $ den_NERLUE                   <dbl> 0.00000, 0.00000, 0.00000, 0.000~
## $ den_MACPYRAD                 <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ den_NERLUEsmall              <int> NA, NA, NA, NA, NA, NA, NA, NA, ~
## $ den_MACSTIPES                <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ npp.mean                     <dbl> 1364.5333, 1364.5333, 1364.5333,~
## $ pdo_mean                     <dbl> -0.3625000, -0.3625000, -0.36250~
## $ npgo_mean                    <dbl> -1.9050000, -1.9050000, -1.90500~
## $ mei_mean                     <dbl> -0.2916667, -0.2916667, -0.29166~
## $ Days_15C                     <int> 4, 4, 4, 4, 4, 4, 0, 0, 0, 0, 0,~
## $ Days_16C                     <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_17C                     <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_18C                     <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_19C                     <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
```

```
## $ Days_20C                                <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_21C                                <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_22C                                <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_23C                                <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_15C                         <dbl> 1.03, 1.03, 1.03, 1.03, 1.03, 1.~
## $ Degree_Days_16C                         <dbl> 0.00, 0.00, 0.00, 0.00, 0.00, 0.~
## $ Degree_Days_17C                         <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_18C                         <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_19C                         <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_20C                         <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_21C                         <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_22C                         <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_23C                         <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Max_Monthly_Anomaly_Summer_Temp         <dbl> 0.9405405, 0.9405405, 0.9405405,~
## $ Max_Monthly_Anomaly_Temp                <dbl> 1.2088579, 1.2088579, 1.2088579,~
## $ Max_Monthly_Anomaly_Upwelling_Temp      <dbl> 0.4936126, 0.4936126, 0.4936126,~
## $ Max_Monthly_Temp_Index                  <int> 10, 10, 10, 10, 10, 10, 9, 9, 9,~
## $ Max_Monthly_Temp                        <dbl> 13.42419, 13.42419, 13.42419, 13~
## $ Mean_Monthly_Summer_Temp                <dbl> 12.26695, 12.26695, 12.26695, 12~
## $ Mean_Monthly_Temp                       <dbl> 11.87421, 11.87421, 11.87421, 11~
## $ Mean_Monthly_Upwelling_Temp             <dbl> 10.941999, 10.941999, 10.941999,~
## $ MHW_Days                                <int> 27, 27, 27, 27, 27, 27, 0, 0, 0,~
## $ MHW_Intensity                           <dbl> 55.82227, 55.82227, 55.82227, 55~
## $ MHW_Summer_Days                         <int> 17, 17, 17, 17, 17, 17, 0, 0, 0,~
## $ MHW_Summer_Intensity                    <dbl> 38.47348, 38.47348, 38.47348, 38~
## $ MHW_Upwelling_Days                      <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ MHW_Upwelling_Intensity                 <dbl> 0.00000, 0.00000, 0.00000, 0.000~
## $ Min_Monthly_Anomaly_Summer_Temp         <dbl> -0.7582432, -0.7582432, -0.75824~
## $ Min_Monthly_Anomaly_Temp                <dbl> -0.7670180, -0.7670180, -0.76701~
## $ Min_Monthly_Anomaly_Upwelling_Temp      <dbl> -0.1944892, -0.1944892, -0.19448~
## $ Min_Monthly_Temp_Index                  <int> 6, 6, 6, 6, 6, 6, 5, 5, 5, 5, 5,~
## $ Min_Monthly_Temp                        <dbl> 10.361333, 10.361333, 10.361333,~
## $ Days_10N                                <int> 70, 70, 70, 70, 70, 70, 91, 91, ~
## $ Days_11N                                <int> 64, 64, 64, 64, 64, 64, 79, 79, ~
## $ Days_12N                                <int> 57, 57, 57, 57, 57, 57, 73, 73, ~
## $ Days_13N                                <int> 49, 49, 49, 49, 49, 49, 66, 66, ~
## $ Days_14N                                <int> 40, 40, 40, 40, 40, 40, 57, 57, ~
## $ Days_15N                                <int> 38, 38, 38, 38, 38, 38, 52, 52, ~
## $ Days_1N                                 <int> 198, 198, 198, 198, 198, 198, 31~
## $ Days_2N                                 <int> 181, 181, 181, 181, 181, 181, 27~
## $ Days_3N                                 <int> 160, 160, 160, 160, 160, 160, 22~
## $ Days_4N                                 <int> 139, 139, 139, 139, 139, 139, 18~
## $ Days_5N                                 <int> 127, 127, 127, 127, 127, 127, 16~
## $ Days_6N                                 <int> 111, 111, 111, 111, 111, 111, 14~
## $ Days_7N                                 <int> 103, 103, 103, 103, 103, 103, 12~
## $ Days_8N                                 <int> 90, 90, 90, 90, 90, 90, 115, 115~
## $ Days_9N                                 <int> 82, 82, 82, 82, 82, 82, 103, 103~
## $ Degree_Days_10N                         <dbl> 380.72462, 380.72462, 380.72462,~
## $ Degree_Days_11N                         <dbl> 313.86470, 313.86470, 313.86470,~
## $ Degree_Days_12N                         <dbl> 253.03910, 253.03910, 253.03910,~
## $ Degree_Days_13N                         <dbl> 200.88361, 200.88361, 200.88361,~
## $ Degree_Days_14N                         <dbl> 156.60688, 156.60688, 156.60688,~
## $ Degree_Days_15N                         <dbl> 117.571951, 117.571951, 117.5719~
## $ Degree_Days_1N                          <dbl> 1513.3439, 1513.3439, 1513.3439,~
```

```
## $ Degree_Days_2N                        <dbl> 1324.2269, 1324.2269, 1324.2269,~
## $ Degree_Days_3N                        <dbl> 1151.4363, 1151.4363, 1151.4363,~
## $ Degree_Days_4N                        <dbl> 998.3203, 998.3203, 998.3203, 99~
## $ Degree_Days_5N                        <dbl> 865.9663, 865.9663, 865.9663, 86~
## $ Degree_Days_6N                        <dbl> 746.4577, 746.4577, 746.4577, 74~
## $ Degree_Days_7N                        <dbl> 638.4387, 638.4387, 638.4387, 63~
## $ Degree_Days_8N                        <dbl> 542.5561, 542.5561, 542.5561, 54~
## $ Degree_Days_9N                        <dbl> 456.72968, 456.72968, 456.72968,~
## $ Max_Monthly_Anomaly_Nitrate           <dbl> 3.9860960, 3.9860960, 3.9860960,~
## $ Max_Monthly_Anomaly_Summer_Nitrate    <dbl> 3.9860960, 3.9860960, 3.9860960,~
## $ Max_Monthly_Anomaly_Upwelling_Nitrate <dbl> 0.5618353, 0.5618353, 0.5618353,~
## $ Max_Monthly_Nitrate_Index             <int> 6, 6, 6, 6, 6, 6, 5, 5, 5, 5, 5,~
## $ Max_Monthly_Nitrate                   <dbl> 13.392856, 13.392856, 13.392856,~
## $ Mean_Monthly_Nitrate                  <dbl> 4.787915, 4.787915, 4.787915, 4.~
## $ Mean_Monthly_Summer_Nitrate           <dbl> 3.754989, 3.754989, 3.754989, 3.~
## $ Mean_Monthly_Upwelling_Nitrate        <dbl> 8.908040, 8.908040, 8.908040, 8.~
## $ Min_Monthly_Anomaly_Nitrate           <dbl> -5.353170, -5.353170, -5.353170,~
## $ Min_Monthly_Anomaly_Summer_Nitrate    <dbl> -2.33496107, -2.33496107, -2.334~
## $ Min_Monthly_Anomaly_Upwelling_Nitrate <dbl> -4.242842, -4.242842, -4.242842,~
## $ Min_Monthly_Nitrate                   <dbl> 0.8870311, 0.8870311, 0.8870311,~
## $ Min_Monthly_Temp_Nitrate              <int> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,~
## $ mean_depth                            <dbl> -0.5695702, -0.5695702, -0.56957~
## $ mean_prob_of_rock                     <dbl> 0.9997463, 0.9997463, 0.9997463,~
## $ mean_vrm                              <dbl> 8.62e-05, 8.62e-05, 8.62e-05, 8.~
## $ mean_slope                            <dbl> 0.8211701, 0.8211701, 0.8211701,~
## $ sd_depth                              <dbl> 1.106474, 1.106474, 1.106474, 1.~
## $ sd_prob_of_rock                       <dbl> 0.001056774, 0.001056774, 0.0010~
## $ sd_vrm                                <dbl> 0.00029503, 0.00029503, 0.000295~
## $ sd_slope                              <dbl> 1.729309, 1.729309, 1.729309, 1.~
## $ min_depth                             <dbl> -4.259407, -4.259407, -4.259407,~
## $ min_prob_of_rock                      <dbl> 0.9947428, 0.9947428, 0.9947428,~
## $ min_vrm                               <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ min_slope                             <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ max_depth                             <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ max_prob_of_rock                      <dbl> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,~
## $ max_vrm                               <dbl> 0.003624092, 0.003624092, 0.0036~
## $ max_slope                             <dbl> 8.586119, 8.586119, 8.586119, 8.~
## $ range_depth                           <dbl> 4.259407, 4.259407, 4.259407, 4.~
## $ range_prob_of_rock                    <dbl> 0.005257189, 0.005257189, 0.0052~
## $ range_vrm                             <dbl> 0.003624092, 0.003624092, 0.0036~
## $ range_slope                           <dbl> 8.586119, 8.586119, 8.586119, 8.~
## $ median_depth                          <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ median_prob_of_rock                   <dbl> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,~
## $ median_vrm                            <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ median_slope                          <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ prop_map_depth                        <dbl> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,~
## $ prop_map_prob_of_rock                 <dbl> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,~
## $ prop_map_vrm                          <dbl> 0.5717566, 0.5717566, 0.5717566,~
## $ prop_map_slope                        <dbl> 0.6613088, 0.6613088, 0.6613088,~
## $ wh_mean                               <dbl> 0.9742126, 0.9742126, 0.9742126,~
## $ wh_max                                <dbl> 2.699128, 2.699128, 2.699128, 2.~
## $ wh_95prc                              <dbl> 1.624681, 1.624681, 1.624681, 1.~
## $ wh_99prc                              <dbl> 2.105916, 2.105916, 2.105916, 2.~
## $ mean_waveyear                         <dbl> 1.0328991, 1.0328991, 1.0328991,~
```

```
## $ max_waveyear                    <dbl> 2.699128, 2.699128, 2.699128, 2.~
## $ wh_95prc_wy                     <dbl> 1.718803, 1.718803, 1.718803, 1.~
## $ wh_99prc_wy                     <dbl> 2.079910, 2.079910, 2.079910, 2.~
## $ UBR_Max                         <int> 467, 467, 467, 467, 467, 467, 38~
## $ UBR_Mean                        <int> 155, 155, 155, 155, 155, 155, 23~
## $ UBRYear_Max                     <int> 467, 467, 467, 467, 467, 467, 38~
## $ UBRYear_Mean                    <int> 232, 232, 232, 232, 232, 232, 23~
## $ Wave_Max                        <int> 3, 3, 3, 3, 3, 3, 2, 2, 2, 2, 2,~
## $ Wave_Mean                       <int> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,~
## $ WaveYear_Max                    <int> 3, 3, 3, 3, 3, 3, 2, 2, 2, 2, 2,~
## $ WaveYear_Mean                   <int> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,~
## $ Max_Monthly_NPP                 <dbl> 5792.267, 5792.267, 5792.267, 57~
## $ Max_Monthly_NPP_Summer          <dbl> 5792.267, 5792.267, 5792.267, 57~
## $ Max_Monthly_NPP_Upwelling       <dbl> 3045.315, 3045.315, 3045.315, 30~
## $ Mean_Monthly_NPP                <dbl> 2106.831, 2106.831, 2106.831, 21~
## $ Mean_Monthly_NPP_Summer         <dbl> 2924.500, 2924.500, 2924.500, 29~
## $ Mean_Monthly_NPP_Upwelling      <dbl> 1781.252, 1781.252, 1781.252, 17~
## $ Min_Monthly_NPP                 <dbl> 698.8677, 698.8677, 698.8677, 69~
## $ Min_Monthly_NPP_Summer          <dbl> 1255.6813, 1255.6813, 1255.6813,~
## $ Min_Monthly_NPP_Upwelling       <dbl> 927.1774, 927.1774, 927.1774, 92~
```

```
## get the sites for North Coast model ----
df.nc <- df %>%
  dplyr::select(-c(latitude, longitude)) %>%
  right_join(ncsites, by = c('site_name')) %>%
  droplevels() %>% #glimpse()
  #dplyr::select(-c(total.years, pre.mhw.years, during.mhw.years, post.mhw.years)) %>%
  relocate(c(latitude, longitude), .after = zone) %>%
  glimpse() # Rows: 708
```

```
## Rows: 708
## Columns: 156
## $ site_name                       <fct> Fort Ross, Fort Ross, Fort Ross,~
## $ month                           <fct> 10, 10, 10, 10, 10, 10, 10, 10, ~
## $ year                            <fct> 2015, 2015, 2015, 2015, 2015, 20~
## $ transect                        <fct> 1, 2, 3, 4, 5, 6, 1, 2, 3, 4, 5,~
## $ zone                            <fct> OUTER, OUTER, OUTER, INNER, INNE~
## $ latitude                        <dbl> 38.5106, 38.5106, 38.5106, 38.51~
## $ longitude                       <dbl> -123.245, -123.245, -123.245, -1~
## $ den_STRPURAD                    <dbl> 55.55556, 20.00000, 750.00000, 5~
## $ den_HALRUF                      <dbl> 55.55556, 9.00000, 50.00000, 55.~
## $ den_MESFRAAD                    <dbl> 46.00000, 55.55556, 7.00000, 35.~
## $ den_PYCHEL                      <int> 0, 0, 0, 0, 0, 0, 0, 6, 0, 0, 2,~
## $ den_NERLUE                      <dbl> 0.00000, 0.00000, 0.00000, 0.000~
## $ den_MACPYRAD                    <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ den_NERLUEsmall                 <int> NA, NA, NA, NA, NA, NA, NA, NA, ~
## $ den_MACSTIPES                   <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ npp.mean                        <dbl> NA, NA, NA, NA, NA, NA, 1133.195~
## $ pdo_mean                        <dbl> 0.920000, 0.920000, 0.920000, 0.~
## $ npgo_mean                       <dbl> -1.3941667, -1.3941667, -1.39416~
## $ mei_mean                        <dbl> 1.28333333, 1.28333333, 1.283333~
## $ Days_15C                        <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_16C                        <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_17C                        <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
```

```
## $ Days_18C                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_19C                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_20C                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_21C                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_22C                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_23C                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_15C                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_16C                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_17C                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_18C                       <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_19C                       <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_20C                       <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_21C                       <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_22C                       <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_23C                       <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Max_Monthly_Anomaly_Summer_Temp       <dbl> 2.86037489, 2.86037489, 2.860374~
## $ Max_Monthly_Anomaly_Temp              <dbl> 2.85233653, 2.85233653, 2.852336~
## $ Max_Monthly_Anomaly_Upwelling_Temp    <dbl> 2.0442495, 2.0442495, 2.0442495,~
## $ Max_Monthly_Temp_Index                <int> 10, 10, 10, 10, 10, 10, 9, 9, 9,~
## $ Max_Monthly_Temp                      <dbl> 15.56290, 15.56290, 15.56290, 15~
## $ Mean_Monthly_Summer_Temp              <dbl> 14.04160, 14.04160, 14.04160, 14~
## $ Mean_Monthly_Temp                     <dbl> 12.93553, 12.93553, 12.93553, 12~
## $ Mean_Monthly_Upwelling_Temp           <dbl> 11.597677, 11.597677, 11.597677,~
## $ MHW_Days                              <int> 167, 167, 167, 167, 167, 167, 5,~
## $ MHW_Intensity                         <dbl> 384.061512, 384.061512, 384.0615~
## $ MHW_Summer_Days                       <int> 94, 94, 94, 94, 94, 94, 5, 5, 5,~
## $ MHW_Summer_Intensity                  <dbl> 250.955777, 250.955777, 250.9557~
## $ MHW_Upwelling_Days                    <int> 33, 33, 33, 33, 33, 33, 0, 0, 0,~
## $ MHW_Upwelling_Intensity               <dbl> 68.16678, 68.16678, 68.16678, 68~
## $ Min_Monthly_Anomaly_Summer_Temp       <dbl> 0.7928108, 0.7928108, 0.7928108,~
## $ Min_Monthly_Anomaly_Temp              <dbl> -0.05073234, -0.05073234, -0.050~
## $ Min_Monthly_Anomaly_Upwelling_Temp    <dbl> -0.04973845, -0.04973845, -0.049~
## $ Min_Monthly_Temp_Index                <int> 5, 5, 5, 5, 5, 5, 4, 4, 4, 4, 4,~
## $ Min_Monthly_Temp                      <dbl> 10.129032, 10.129032, 10.129032,~
## $ Days_10N                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_11N                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_12N                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_13N                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_14N                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_15N                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_1N                               <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_2N                               <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_3N                               <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_4N                               <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_5N                               <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_6N                               <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_7N                               <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_8N                               <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Days_9N                               <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_10N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_11N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_12N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_13N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_14N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
```

```
## $ Degree_Days_15N                      <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_1N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_2N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_3N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_4N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_5N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_6N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_7N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_8N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Degree_Days_9N                       <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Max_Monthly_Anomaly_Nitrate          <dbl> 0.4776073, 0.4776073, 0.4776073,~
## $ Max_Monthly_Anomaly_Summer_Nitrate   <dbl> -0.4975728, -0.4975728, -0.49757~
## $ Max_Monthly_Anomaly_Upwelling_Nitrate <dbl> 0.4776073, 0.4776073, 0.4776073,~
## $ Max_Monthly_Nitrate_Index            <int> 5, 5, 5, 5, 5, 5, 4, 4, 4, 4, 4,~
## $ Max_Monthly_Nitrate                  <dbl> 15.50432, 15.50432, 15.50432, 15~
## $ Mean_Monthly_Nitrate                 <dbl> 2.951467, 2.951467, 2.951467, 2.~
## $ Mean_Monthly_Summer_Nitrate          <dbl> 1.290271, 1.290271, 1.290271, 1.~
## $ Mean_Monthly_Upwelling_Nitrate       <dbl> 7.056086, 7.056086, 7.056086, 7.~
## $ Min_Monthly_Anomaly_Nitrate          <dbl> -8.0158185, -8.0158185, -8.01581~
## $ Min_Monthly_Anomaly_Summer_Nitrate   <dbl> -6.5534900, -6.5534900, -6.55349~
## $ Min_Monthly_Anomaly_Upwelling_Nitrate <dbl> -8.015819, -8.015819, -8.015819,~
## $ Min_Monthly_Nitrate                  <dbl> 0.0000000, 0.0000000, 0.0000000,~
## $ Min_Monthly_Temp_Nitrate             <int> 1, 1, 1, 1, 1, 1, 6, 6, 6, 6, 6,~
## $ mean_depth                           <dbl> -9.040727, -9.040727, -9.040727,~
## $ mean_prob_of_rock                    <dbl> 0.6323734, 0.6323734, 0.6323734,~
## $ mean_vrm                             <dbl> 0.000137088, 0.000137088, 0.0001~
## $ mean_slope                           <dbl> 3.476603, 3.476603, 3.476603, 3.~
## $ sd_depth                             <dbl> 3.48555, 3.48555, 3.48555, 3.485~
## $ sd_prob_of_rock                      <dbl> 0.3317136, 0.3317136, 0.3317136,~
## $ sd_vrm                               <dbl> 0.000209537, 0.000209537, 0.0002~
## $ sd_slope                             <dbl> 0.7030445, 0.7030445, 0.7030445,~
## $ min_depth                            <dbl> -16.12281, -16.12281, -16.12281,~
## $ min_prob_of_rock                     <dbl> 5.66e-05, 5.66e-05, 5.66e-05, 5.~
## $ min_vrm                              <dbl> 1.34e-05, 1.34e-05, 1.34e-05, 1.~
## $ min_slope                            <dbl> 1.867539, 1.867539, 1.867539, 1.~
## $ max_depth                            <dbl> -2.433142, -2.433142, -2.433142,~
## $ max_prob_of_rock                     <dbl> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,~
## $ max_vrm                              <dbl> 0.000919998, 0.000919998, 0.0009~
## $ max_slope                            <dbl> 5.07899, 5.07899, 5.07899, 5.078~
## $ range_depth                          <dbl> 13.68967, 13.68967, 13.68967, 13~
## $ range_prob_of_rock                   <dbl> 0.9999434, 0.9999434, 0.9999434,~
## $ range_vrm                            <dbl> 0.000906646, 0.000906646, 0.0009~
## $ range_slope                          <dbl> 3.211451, 3.211451, 3.211451, 3.~
## $ median_depth                         <dbl> -8.798749, -8.798749, -8.798749,~
## $ median_prob_of_rock                  <dbl> 0.6991448, 0.6991448, 0.6991448,~
## $ median_vrm                           <dbl> 7.13e-05, 7.13e-05, 7.13e-05, 7.~
## $ median_slope                         <dbl> 3.382058, 3.382058, 3.382058, 3.~
## $ prop_map_depth                       <dbl> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,~
## $ prop_map_prob_of_rock                <dbl> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,~
## $ prop_map_vrm                         <dbl> 0.4444444, 0.4444444, 0.4444444,~
## $ prop_map_slope                       <dbl> 0.6666667, 0.6666667, 0.6666667,~
## $ wh_mean                              <dbl> 1.406087, 1.406087, 1.406087, 1.~
## $ wh_max                               <dbl> 6.918628, 6.918628, 6.918628, 6.~
## $ wh_95prc                             <dbl> 2.832922, 2.832922, 2.832922, 2.~
```

```
## $ wh_99prc                          <dbl> 4.722291, 4.722291, 4.722291, 4.~
## $ mean_waveyear                     <dbl> 1.731754, 1.731754, 1.731754, 1.~
## $ max_waveyear                      <dbl> 4.779284, 4.779284, 4.779284, 4.~
## $ wh_95prc_wy                       <dbl> 3.555114, 3.555114, 3.555114, 3.~
## $ wh_99prc_wy                       <dbl> 4.290092, 4.290092, 4.290092, 4.~
## $ UBR_Max                           <int> 243, 243, 243, 243, 243, 243, 13~
## $ UBR_Mean                          <int> 50, 50, 50, 50, 50, 50, 65, 65, ~
## $ UBRYear_Max                       <int> 163, 163, 163, 163, 163, 163, 13~
## $ UBRYear_Mean                      <int> 67, 67, 67, 67, 67, 67, 65, 65, ~
## $ Wave_Max                          <int> 7, 7, 7, 7, 7, 7, 4, 4, 4, 4, 4,~
## $ Wave_Mean                         <int> 1, 1, 1, 1, 1, 1, 2, 2, 2, 2, 2,~
## $ WaveYear_Max                      <int> 5, 5, 5, 5, 5, 5, 4, 4, 4, 4, 4,~
## $ WaveYear_Mean                     <int> 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2,~
## $ Max_Monthly_NPP                   <dbl> 7337.850, 7337.850, 7337.850, 73~
## $ Max_Monthly_NPP_Summer            <dbl> 7337.850, 7337.850, 7337.850, 73~
## $ Max_Monthly_NPP_Upwelling         <dbl> 5837.788, 5837.788, 5837.788, 58~
## $ Mean_Monthly_NPP                  <dbl> 3014.864, 3014.864, 3014.864, 30~
## $ Mean_Monthly_NPP_Summer           <dbl> 3491.858, 3491.858, 3491.858, 34~
## $ Mean_Monthly_NPP_Upwelling        <dbl> 3246.272, 3246.272, 3246.272, 32~
## $ Min_Monthly_NPP                   <dbl> 984.9625, 984.9625, 984.9625, 98~
## $ Min_Monthly_NPP_Summer            <dbl> 1313.652, 1313.652, 1313.652, 13~
## $ Min_Monthly_NPP_Upwelling         <dbl> 1300.4202, 1300.4202, 1300.4202,~
## $ total.years                       <int> 15, 15, 15, 15, 15, 15, 15, 15, ~
## $ pre.mhw.years                     <int> 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7,~
## $ during.mhw.years                  <int> 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3,~
## $ post.mhw.years                    <int> 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5,~
```

```
length(levels(df.nc$site_name)) # 10
```

```
## [1] 10
```

```
levels(df.nc$site_name)
```

```
##  [1] "Fort Ross"            "Gerstle Cove"         "Mendocino Headlands"
##  [4] "Ocean Cove"           "Point Arena MPA (M2)" "Point Arena Ref"
##  [7] "Portuguese Beach"     "Stillwater Sonoma"    "Stornetta"
## [10] "Van Damme"
```

```
any(is.na(df.nc$Max_Monthly_Anomaly_Temp)) # FALSE
```

```
## [1] FALSE
```

2. Choose variables and transform needed

```
names(df.nc)
```

```
##   [1] "site_name"
##   [2] "month"
##   [3] "year"
```

```
##   [4] "transect"
##   [5] "zone"
##   [6] "latitude"
##   [7] "longitude"
##   [8] "den_STRPURAD"
##   [9] "den_HALRUF"
##  [10] "den_MESFRAAD"
##  [11] "den_PYCHEL"
##  [12] "den_NERLUE"
##  [13] "den_MACPYRAD"
##  [14] "den_NERLUEsmall"
##  [15] "den_MACSTIPES"
##  [16] "npp.mean"
##  [17] "pdo_mean"
##  [18] "npgo_mean"
##  [19] "mei_mean"
##  [20] "Days_15C"
##  [21] "Days_16C"
##  [22] "Days_17C"
##  [23] "Days_18C"
##  [24] "Days_19C"
##  [25] "Days_20C"
##  [26] "Days_21C"
##  [27] "Days_22C"
##  [28] "Days_23C"
##  [29] "Degree_Days_15C"
##  [30] "Degree_Days_16C"
##  [31] "Degree_Days_17C"
##  [32] "Degree_Days_18C"
##  [33] "Degree_Days_19C"
##  [34] "Degree_Days_20C"
##  [35] "Degree_Days_21C"
##  [36] "Degree_Days_22C"
##  [37] "Degree_Days_23C"
##  [38] "Max_Monthly_Anomaly_Summer_Temp"
##  [39] "Max_Monthly_Anomaly_Temp"
##  [40] "Max_Monthly_Anomaly_Upwelling_Temp"
##  [41] "Max_Monthly_Temp_Index"
##  [42] "Max_Monthly_Temp"
##  [43] "Mean_Monthly_Summer_Temp"
##  [44] "Mean_Monthly_Temp"
##  [45] "Mean_Monthly_Upwelling_Temp"
##  [46] "MHW_Days"
##  [47] "MHW_Intensity"
##  [48] "MHW_Summer_Days"
##  [49] "MHW_Summer_Intensity"
##  [50] "MHW_Upwelling_Days"
##  [51] "MHW_Upwelling_Intensity"
##  [52] "Min_Monthly_Anomaly_Summer_Temp"
##  [53] "Min_Monthly_Anomaly_Temp"
##  [54] "Min_Monthly_Anomaly_Upwelling_Temp"
##  [55] "Min_Monthly_Temp_Index"
##  [56] "Min_Monthly_Temp"
##  [57] "Days_10N"
```

```
##  [58] "Days_11N"
##  [59] "Days_12N"
##  [60] "Days_13N"
##  [61] "Days_14N"
##  [62] "Days_15N"
##  [63] "Days_1N"
##  [64] "Days_2N"
##  [65] "Days_3N"
##  [66] "Days_4N"
##  [67] "Days_5N"
##  [68] "Days_6N"
##  [69] "Days_7N"
##  [70] "Days_8N"
##  [71] "Days_9N"
##  [72] "Degree_Days_10N"
##  [73] "Degree_Days_11N"
##  [74] "Degree_Days_12N"
##  [75] "Degree_Days_13N"
##  [76] "Degree_Days_14N"
##  [77] "Degree_Days_15N"
##  [78] "Degree_Days_1N"
##  [79] "Degree_Days_2N"
##  [80] "Degree_Days_3N"
##  [81] "Degree_Days_4N"
##  [82] "Degree_Days_5N"
##  [83] "Degree_Days_6N"
##  [84] "Degree_Days_7N"
##  [85] "Degree_Days_8N"
##  [86] "Degree_Days_9N"
##  [87] "Max_Monthly_Anomaly_Nitrate"
##  [88] "Max_Monthly_Anomaly_Summer_Nitrate"
##  [89] "Max_Monthly_Anomaly_Upwelling_Nitrate"
##  [90] "Max_Monthly_Nitrate_Index"
##  [91] "Max_Monthly_Nitrate"
##  [92] "Mean_Monthly_Nitrate"
##  [93] "Mean_Monthly_Summer_Nitrate"
##  [94] "Mean_Monthly_Upwelling_Nitrate"
##  [95] "Min_Monthly_Anomaly_Nitrate"
##  [96] "Min_Monthly_Anomaly_Summer_Nitrate"
##  [97] "Min_Monthly_Anomaly_Upwelling_Nitrate"
##  [98] "Min_Monthly_Nitrate"
##  [99] "Min_Monthly_Temp_Nitrate"
## [100] "mean_depth"
## [101] "mean_prob_of_rock"
## [102] "mean_vrm"
## [103] "mean_slope"
## [104] "sd_depth"
## [105] "sd_prob_of_rock"
## [106] "sd_vrm"
## [107] "sd_slope"
## [108] "min_depth"
## [109] "min_prob_of_rock"
## [110] "min_vrm"
## [111] "min_slope"
```

```
## [112] "max_depth"
## [113] "max_prob_of_rock"
## [114] "max_vrm"
## [115] "max_slope"
## [116] "range_depth"
## [117] "range_prob_of_rock"
## [118] "range_vrm"
## [119] "range_slope"
## [120] "median_depth"
## [121] "median_prob_of_rock"
## [122] "median_vrm"
## [123] "median_slope"
## [124] "prop_map_depth"
## [125] "prop_map_prob_of_rock"
## [126] "prop_map_vrm"
## [127] "prop_map_slope"
## [128] "wh_mean"
## [129] "wh_max"
## [130] "wh_95prc"
## [131] "wh_99prc"
## [132] "mean_waveyear"
## [133] "max_waveyear"
## [134] "wh_95prc_wy"
## [135] "wh_99prc_wy"
## [136] "UBR_Max"
## [137] "UBR_Mean"
## [138] "UBRYear_Max"
## [139] "UBRYear_Mean"
## [140] "Wave_Max"
## [141] "Wave_Mean"
## [142] "WaveYear_Max"
## [143] "WaveYear_Mean"
## [144] "Max_Monthly_NPP"
## [145] "Max_Monthly_NPP_Summer"
## [146] "Max_Monthly_NPP_Upwelling"
## [147] "Mean_Monthly_NPP"
## [148] "Mean_Monthly_NPP_Summer"
## [149] "Mean_Monthly_NPP_Upwelling"
## [150] "Min_Monthly_NPP"
## [151] "Min_Monthly_NPP_Summer"
## [152] "Min_Monthly_NPP_Upwelling"
## [153] "total.years"
## [154] "pre.mhw.years"
## [155] "during.mhw.years"
## [156] "post.mhw.years"
```

```
dat1 <- df.nc %>%
  dplyr::select(
    # Factors
    latitude, longitude,
    site_name, year, transect, zone,
    # Bio vars
    den_NERLUE , den_MESFRAAD , den_STRPURAD , den_PYCHEL, den_HALRUF,
    # Nitrate vars
```

```
  Days_10N,
  Min_Monthly_Nitrate,
  Max_Monthly_Nitrate,
  Mean_Monthly_Nitrate,
  Mean_Monthly_Upwelling_Nitrate,
  Max_Monthly_Anomaly_Nitrate,
  Mean_Monthly_Summer_Nitrate,
  # Temperature vars
  Days_16C ,
  Mean_Monthly_Temp ,
  Mean_Monthly_Summer_Temp,
  MHW_Upwelling_Days  ,
  Min_Monthly_Anomaly_Temp,
  Max_Monthly_Anomaly_Upwelling_Temp,
  Min_Monthly_Temp,
  Mean_Monthly_Upwelling_Temp,
  #wh.95 ,   wh.max,
  npgo_mean , mei_mean,
  # substrate
  mean_depth, mean_prob_of_rock, mean_vrm, mean_slope,
  # waves
  wh_max, wh_mean, mean_waveyear, wh_95prc,
  # Orb vel
  UBR_Mean, UBR_Max,
  # NPP
  Mean_Monthly_NPP, Max_Monthly_NPP_Upwelling, Mean_Monthly_NPP_Upwelling, Min_Monthly_NPP,
) %>%
# Bio transformations
mutate(log_den_NERLUE = log(den_NERLUE + 1),
       log_den_MESFRAAD = log(den_MESFRAAD + 1),
       log_den_STRPURAD = log(den_STRPURAD + 1),
       log_den_PYCHEL = log(den_PYCHEL + 1),
       log_den_HALRUF = log(den_HALRUF + 1),
       log_mean_vrm = log(mean_vrm + 1)) %>%
dplyr::select(-c(den_NERLUE,
                 den_MESFRAAD,
                 den_STRPURAD,
                 den_PYCHEL,
                 den_HALRUF,
                 mean_vrm)) %>%
# Temperature transformations
mutate(log_Days_16C = log(Days_16C + 1)) %>%
dplyr::select(-c(Days_16C)) %>%
# Orb vel transformations
mutate(log_UBR_Mean = log(UBR_Mean + 1),
       log_UBR_Max = log(UBR_Max +1)) %>%
dplyr::select(-c(UBR_Mean,
                 UBR_Max)) %>%
# NPP transformations
mutate(log_Mean_Monthly_NPP_Upwelling = log(Mean_Monthly_NPP_Upwelling + 1),
       log_Min_Monthly_NPP = log(Min_Monthly_NPP + 1)) %>%
dplyr::select(-c(Mean_Monthly_NPP_Upwelling,
                 Min_Monthly_NPP)) %>%
```

```
  glimpse() # Rows: 708
```

```
## Rows: 708
## Columns: 42
## $ latitude                             <dbl> 38.5106, 38.5106, 38.5106, 38.5106,~
## $ longitude                            <dbl> -123.245, -123.245, -123.245, -123.~
## $ site_name                            <fct> Fort Ross, Fort Ross, Fort Ross, Fo~
## $ year                                 <fct> 2015, 2015, 2015, 2015, 2015, 2015,~
## $ transect                             <fct> 1, 2, 3, 4, 5, 6, 1, 2, 3, 4, 5, 6,~
## $ zone                                 <fct> OUTER, OUTER, OUTER, INNER, INNER, ~
## $ Days_10N                             <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Min_Monthly_Nitrate                  <dbl> 0.0000000, 0.0000000, 0.0000000, 0.~
## $ Max_Monthly_Nitrate                  <dbl> 15.50432, 15.50432, 15.50432, 15.50~
## $ Mean_Monthly_Nitrate                 <dbl> 2.951467, 2.951467, 2.951467, 2.951~
## $ Mean_Monthly_Upwelling_Nitrate       <dbl> 7.056086, 7.056086, 7.056086, 7.056~
## $ Max_Monthly_Anomaly_Nitrate          <dbl> 0.4776073, 0.4776073, 0.4776073, 0.~
## $ Mean_Monthly_Summer_Nitrate          <dbl> 1.290271, 1.290271, 1.290271, 1.290~
## $ Mean_Monthly_Temp                    <dbl> 12.93553, 12.93553, 12.93553, 12.93~
## $ Mean_Monthly_Summer_Temp             <dbl> 14.04160, 14.04160, 14.04160, 14.04~
## $ MHW_Upwelling_Days                   <int> 33, 33, 33, 33, 33, 33, 0, 0, 0, 0,~
## $ Min_Monthly_Anomaly_Temp             <dbl> -0.05073234, -0.05073234, -0.050732~
## $ Max_Monthly_Anomaly_Upwelling_Temp   <dbl> 2.0442495, 2.0442495, 2.0442495, 2.~
## $ Min_Monthly_Temp                     <dbl> 10.129032, 10.129032, 10.129032, 10~
## $ Mean_Monthly_Upwelling_Temp          <dbl> 11.597677, 11.597677, 11.597677, 11~
## $ npgo_mean                            <dbl> -1.3941667, -1.3941667, -1.3941667,~
## $ mei_mean                             <dbl> 1.28333333, 1.28333333, 1.28333333,~
## $ mean_depth                           <dbl> -9.040727, -9.040727, -9.040727, -9~
## $ mean_prob_of_rock                    <dbl> 0.6323734, 0.6323734, 0.6323734, 0.~
## $ mean_slope                           <dbl> 3.476603, 3.476603, 3.476603, 3.476~
## $ wh_max                               <dbl> 6.918628, 6.918628, 6.918628, 6.918~
## $ wh_mean                              <dbl> 1.406087, 1.406087, 1.406087, 1.406~
## $ mean_waveyear                        <dbl> 1.731754, 1.731754, 1.731754, 1.731~
## $ wh_95prc                             <dbl> 2.832922, 2.832922, 2.832922, 2.832~
## $ Mean_Monthly_NPP                     <dbl> 3014.864, 3014.864, 3014.864, 3014.~
## $ Max_Monthly_NPP_Upwelling            <dbl> 5837.788, 5837.788, 5837.788, 5837.~
## $ log_den_NERLUE                       <dbl> 0.000000, 0.000000, 0.000000, 0.000~
## $ log_den_MESFRAAD                     <dbl> 3.8501476, 4.0352234, 2.0794415, 3.~
## $ log_den_STRPURAD                     <dbl> 4.0352234, 3.0445224, 6.6214057, 4.~
## $ log_den_PYCHEL                       <dbl> 0.0000000, 0.0000000, 0.0000000, 0.~
## $ log_den_HALRUF                       <dbl> 4.0352234, 2.3025851, 3.9318256, 4.~
## $ log_mean_vrm                         <dbl> 0.0001370786, 0.0001370786, 0.00013~
## $ log_Days_16C                         <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ log_UBR_Mean                         <dbl> 3.931826, 3.931826, 3.931826, 3.931~
## $ log_UBR_Max                          <dbl> 5.497168, 5.497168, 5.497168, 5.497~
## $ log_Mean_Monthly_NPP_Upwelling       <dbl> 8.085571, 8.085571, 8.085571, 8.085~
## $ log_Min_Monthly_NPP                  <dbl> 6.893618, 6.893618, 6.893618, 6.893~
```

```
#### Drop NAs ----
dat2 <- dat1 %>%
  drop_na() %>%
  glimpse() # Rows: 686
```

```
## Rows: 686
```

```
## Columns: 42
## $ latitude                              <dbl> 38.5106, 38.5106, 38.5106, 38.5106,~
## $ longitude                             <dbl> -123.245, -123.245, -123.245, -123.~
## $ site_name                             <fct> Fort Ross, Fort Ross, Fort Ross, Fo~
## $ year                                  <fct> 2015, 2015, 2015, 2015, 2015, 2015,~
## $ transect                              <fct> 1, 2, 3, 4, 5, 6, 1, 2, 3, 4, 5, 6,~
## $ zone                                  <fct> OUTER, OUTER, OUTER, INNER, INNER, ~
## $ Days_10N                              <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Min_Monthly_Nitrate                   <dbl> 0.0000000, 0.0000000, 0.0000000, 0.~
## $ Max_Monthly_Nitrate                   <dbl> 15.50432, 15.50432, 15.50432, 15.50~
## $ Mean_Monthly_Nitrate                  <dbl> 2.951467, 2.951467, 2.951467, 2.951~
## $ Mean_Monthly_Upwelling_Nitrate        <dbl> 7.056086, 7.056086, 7.056086, 7.056~
## $ Max_Monthly_Anomaly_Nitrate           <dbl> 0.4776073, 0.4776073, 0.4776073, 0.~
## $ Mean_Monthly_Summer_Nitrate           <dbl> 1.290271, 1.290271, 1.290271, 1.290~
## $ Mean_Monthly_Temp                     <dbl> 12.93553, 12.93553, 12.93553, 12.93~
## $ Mean_Monthly_Summer_Temp              <dbl> 14.04160, 14.04160, 14.04160, 14.04~
## $ MHW_Upwelling_Days                    <int> 33, 33, 33, 33, 33, 33, 0, 0, 0, 0,~
## $ Min_Monthly_Anomaly_Temp              <dbl> -0.05073234, -0.05073234, -0.050732~
## $ Max_Monthly_Anomaly_Upwelling_Temp    <dbl> 2.0442495, 2.0442495, 2.0442495, 2.~
## $ Min_Monthly_Temp                      <dbl> 10.129032, 10.129032, 10.129032, 10~
## $ Mean_Monthly_Upwelling_Temp           <dbl> 11.597677, 11.597677, 11.597677, 11~
## $ npgo_mean                             <dbl> -1.3941667, -1.3941667, -1.3941667,~
## $ mei_mean                              <dbl> 1.28333333, 1.28333333, 1.28333333,~
## $ mean_depth                            <dbl> -9.040727, -9.040727, -9.040727, -9~
## $ mean_prob_of_rock                     <dbl> 0.6323734, 0.6323734, 0.6323734, 0.~
## $ mean_slope                            <dbl> 3.476603, 3.476603, 3.476603, 3.476~
## $ wh_max                                <dbl> 6.918628, 6.918628, 6.918628, 6.918~
## $ wh_mean                               <dbl> 1.406087, 1.406087, 1.406087, 1.406~
## $ mean_waveyear                         <dbl> 1.731754, 1.731754, 1.731754, 1.731~
## $ wh_95prc                              <dbl> 2.832922, 2.832922, 2.832922, 2.832~
## $ Mean_Monthly_NPP                      <dbl> 3014.864, 3014.864, 3014.864, 3014.~
## $ Max_Monthly_NPP_Upwelling             <dbl> 5837.788, 5837.788, 5837.788, 5837.~
## $ log_den_NERLUE                        <dbl> 0.000000, 0.000000, 0.000000, 0.000~
## $ log_den_MESFRAAD                      <dbl> 3.8501476, 4.0352234, 2.0794415, 3.~
## $ log_den_STRPURAD                      <dbl> 4.0352234, 3.0445224, 6.6214057, 4.~
## $ log_den_PYCHEL                        <dbl> 0.0000000, 0.0000000, 0.0000000, 0.~
## $ log_den_HALRUF                        <dbl> 4.0352234, 2.3025851, 3.9318256, 4.~
## $ log_mean_vrm                          <dbl> 0.0001370786, 0.0001370786, 0.00013~
## $ log_Days_16C                          <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ log_UBR_Mean                          <dbl> 3.931826, 3.931826, 3.931826, 3.931~
## $ log_UBR_Max                           <dbl> 5.497168, 5.497168, 5.497168, 5.497~
## $ log_Mean_Monthly_NPP_Upwelling        <dbl> 8.085571, 8.085571, 8.085571, 8.085~
## $ log_Min_Monthly_NPP                   <dbl> 6.893618, 6.893618, 6.893618, 6.893~
```

```
glimpse(dat2)
```

```
## Rows: 686
## Columns: 42
## $ latitude                              <dbl> 38.5106, 38.5106, 38.5106, 38.5106,~
## $ longitude                             <dbl> -123.245, -123.245, -123.245, -123.~
## $ site_name                             <fct> Fort Ross, Fort Ross, Fort Ross, Fo~
## $ year                                  <fct> 2015, 2015, 2015, 2015, 2015, 2015,~
## $ transect                              <fct> 1, 2, 3, 4, 5, 6, 1, 2, 3, 4, 5, 6,~
## $ zone                                  <fct> OUTER, OUTER, OUTER, INNER, INNER, ~
```

```
## $ Days_10N                            <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ Min_Monthly_Nitrate                 <dbl> 0.0000000, 0.0000000, 0.0000000, 0.~
## $ Max_Monthly_Nitrate                 <dbl> 15.50432, 15.50432, 15.50432, 15.50~
## $ Mean_Monthly_Nitrate                <dbl> 2.951467, 2.951467, 2.951467, 2.951~
## $ Mean_Monthly_Upwelling_Nitrate      <dbl> 7.056086, 7.056086, 7.056086, 7.056~
## $ Max_Monthly_Anomaly_Nitrate         <dbl> 0.4776073, 0.4776073, 0.4776073, 0.~
## $ Mean_Monthly_Summer_Nitrate         <dbl> 1.290271, 1.290271, 1.290271, 1.290~
## $ Mean_Monthly_Temp                   <dbl> 12.93553, 12.93553, 12.93553, 12.93~
## $ Mean_Monthly_Summer_Temp            <dbl> 14.04160, 14.04160, 14.04160, 14.04~
## $ MHW_Upwelling_Days                  <int> 33, 33, 33, 33, 33, 33, 0, 0, 0, 0,~
## $ Min_Monthly_Anomaly_Temp            <dbl> -0.05073234, -0.05073234, -0.050732~
## $ Max_Monthly_Anomaly_Upwelling_Temp <dbl> 2.0442495, 2.0442495, 2.0442495, 2.~
## $ Min_Monthly_Temp                    <dbl> 10.129032, 10.129032, 10.129032, 10~
## $ Mean_Monthly_Upwelling_Temp         <dbl> 11.597677, 11.597677, 11.597677, 11~
## $ npgo_mean                           <dbl> -1.3941667, -1.3941667, -1.3941667,~
## $ mei_mean                            <dbl> 1.28333333, 1.28333333, 1.28333333,~
## $ mean_depth                          <dbl> -9.040727, -9.040727, -9.040727, -9~
## $ mean_prob_of_rock                   <dbl> 0.6323734, 0.6323734, 0.6323734, 0.~
## $ mean_slope                          <dbl> 3.476603, 3.476603, 3.476603, 3.476~
## $ wh_max                              <dbl> 6.918628, 6.918628, 6.918628, 6.918~
## $ wh_mean                             <dbl> 1.406087, 1.406087, 1.406087, 1.406~
## $ mean_waveyear                       <dbl> 1.731754, 1.731754, 1.731754, 1.731~
## $ wh_95prc                            <dbl> 2.832922, 2.832922, 2.832922, 2.832~
## $ Mean_Monthly_NPP                    <dbl> 3014.864, 3014.864, 3014.864, 3014.~
## $ Max_Monthly_NPP_Upwelling           <dbl> 5837.788, 5837.788, 5837.788, 5837.~
## $ log_den_NERLUE                      <dbl> 0.000000, 0.000000, 0.000000, 0.000~
## $ log_den_MESFRAAD                    <dbl> 3.8501476, 4.0352234, 2.0794415, 3.~
## $ log_den_STRPURAD                    <dbl> 4.0352234, 3.0445224, 6.6214057, 4.~
## $ log_den_PYCHEL                      <dbl> 0.0000000, 0.0000000, 0.0000000, 0.~
## $ log_den_HALRUF                      <dbl> 4.0352234, 2.3025851, 3.9318256, 4.~
## $ log_mean_vrm                        <dbl> 0.0001370786, 0.0001370786, 0.00013~
## $ log_Days_16C                        <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,~
## $ log_UBR_Mean                        <dbl> 3.931826, 3.931826, 3.931826, 3.931~
## $ log_UBR_Max                         <dbl> 5.497168, 5.497168, 5.497168, 5.497~
## $ log_Mean_Monthly_NPP_Upwelling      <dbl> 8.085571, 8.085571, 8.085571, 8.085~
## $ log_Min_Monthly_NPP                 <dbl> 6.893618, 6.893618, 6.893618, 6.893~
```

```
levels(dat2$year)
```

```
##  [1] "2006" "2007" "2008" "2009" "2010" "2011" "2012" "2013" "2014" "2015"
## [11] "2016" "2017" "2018" "2019" "2020" "2021"
```

3. Divide data into train and test

```
# Split data into a training set (75%), and a testing set (25%)
inTraining <- createDataPartition(dat2$log_den_NERLUE, p = 0.75, list = FALSE)
train.gam <- dat2[ inTraining,]
test.gam  <- dat2[-inTraining,]
```

4. Run GAM

```
gam1 <- gam(formula = log_den_NERLUE ~
              s(log_den_STRPURAD, k = 5, bs = "cr") +
              s(Max_Monthly_Nitrate, k = 5, bs = "cr") +
              s(wh_max, k = 5, bs = "cr") +
              s(log_UBR_Max, k = 4, bs = "cr") +
              s(site_name, zone, bs = "re") +
              s(year, bs = "re"),
            family = tw(), data = dat2, method = "REML")
```

5. Check GAM

```
gam1$aic
```

```
## [1] 1684.045
```

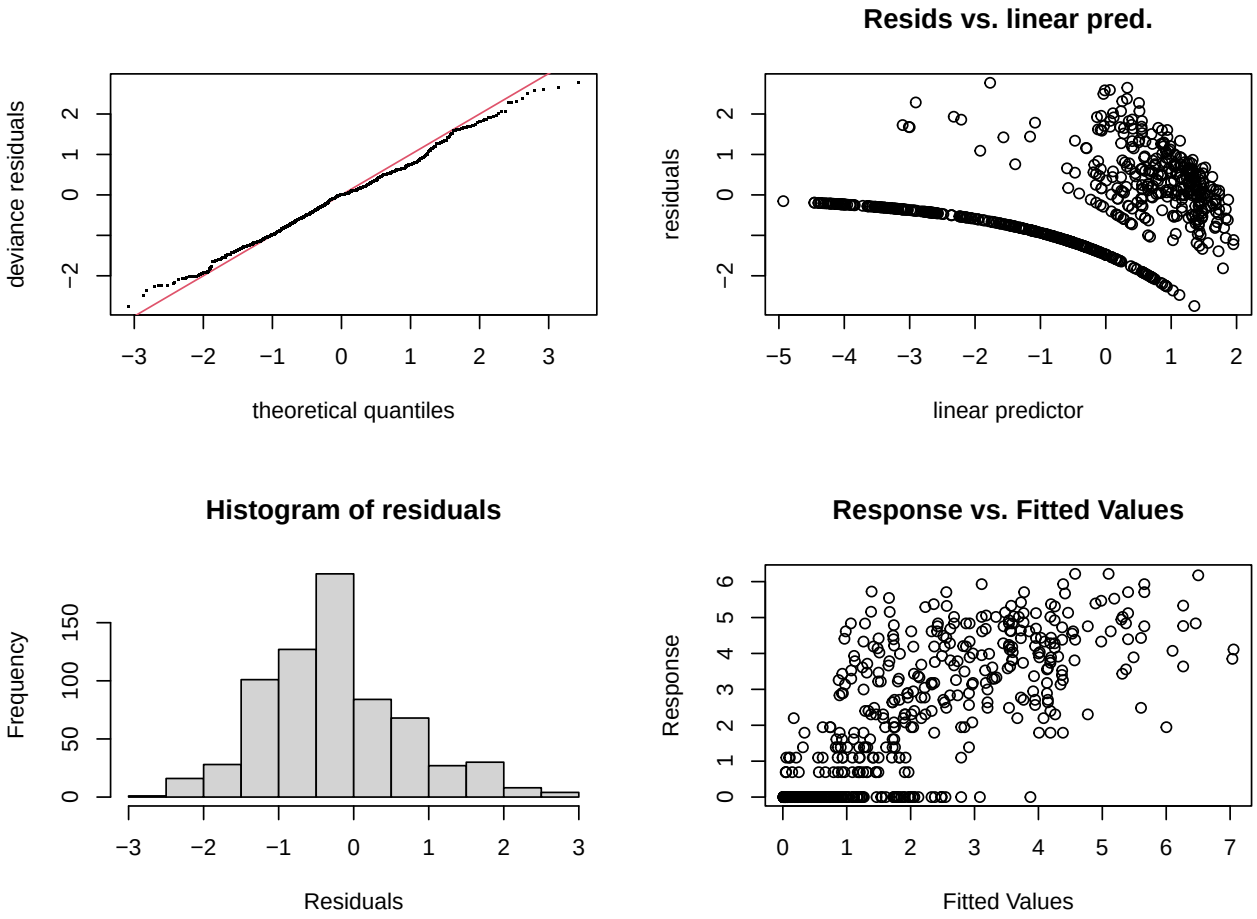
```
gam1$deviance
```

```
## [1] 650.3355
```

```
summary(gam1)
```

```
##
## Family: Tweedie(p=1.085)
## Link function: log
##
## Formula:
## log_den_NERLUE ~ s(log_den_STRPURAD, k = 5, bs = "cr") + s(Max_Monthly_Nitrate,
##     k = 5, bs = "cr") + s(wh_max, k = 5, bs = "cr") + s(log_UBR_Max,
##     k = 4, bs = "cr") + s(site_name, zone, bs = "re") + s(year,
##     bs = "re")
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -0.5254     0.3789  -1.387    0.166
##
## Approximate significance of smooth terms:
##                            edf Ref.df      F  p-value
## s(log_den_STRPURAD)      2.358  2.680  8.543 6.17e-05 ***
## s(Max_Monthly_Nitrate)   3.294  3.651 11.159  < 2e-16 ***
## s(wh_max)                3.698  3.918 10.613  < 2e-16 ***
## s(log_UBR_Max)           2.667  2.884  7.611 0.000286 ***
## s(site_name,zone)       15.335 19.000  4.033 2.31e-05 ***
## s(year)                 12.784 15.000  9.229  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.623   Deviance explained = 64.5%
## -REML = 880.45  Scale est. = 1.3074    n = 686
```

```
gam.check(gam1)
```




```
##
## Method: REML   Optimizer: outer newton
## full convergence after 8 iterations.
## Gradient range [-2.23194e-08,3.732632e-09]
## (score 880.4514 & scale 1.30745).
## Hessian positive definite, eigenvalue range [0.5091827,617.4705].
## Model rank =  52 / 52
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##                          k'   edf k-index p-value
## s(log_den_STRPURAD)     4.00  2.36    0.80  <2e-16 ***
## s(Max_Monthly_Nitrate)  4.00  3.29    0.59  <2e-16 ***
## s(wh_max)               4.00  3.70    0.59  <2e-16 ***
## s(log_UBR_Max)          3.00  2.67    0.62  <2e-16 ***
## s(site_name,zone)      20.00 15.33      NA      NA
## s(year)                16.00 12.78      NA      NA
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# visualize responses
par(mfrow = c(3, 3), mar = c(2, 4, 3, 1))
visreg(gam1)
dev.off()
```

```
## null device
##           1
```

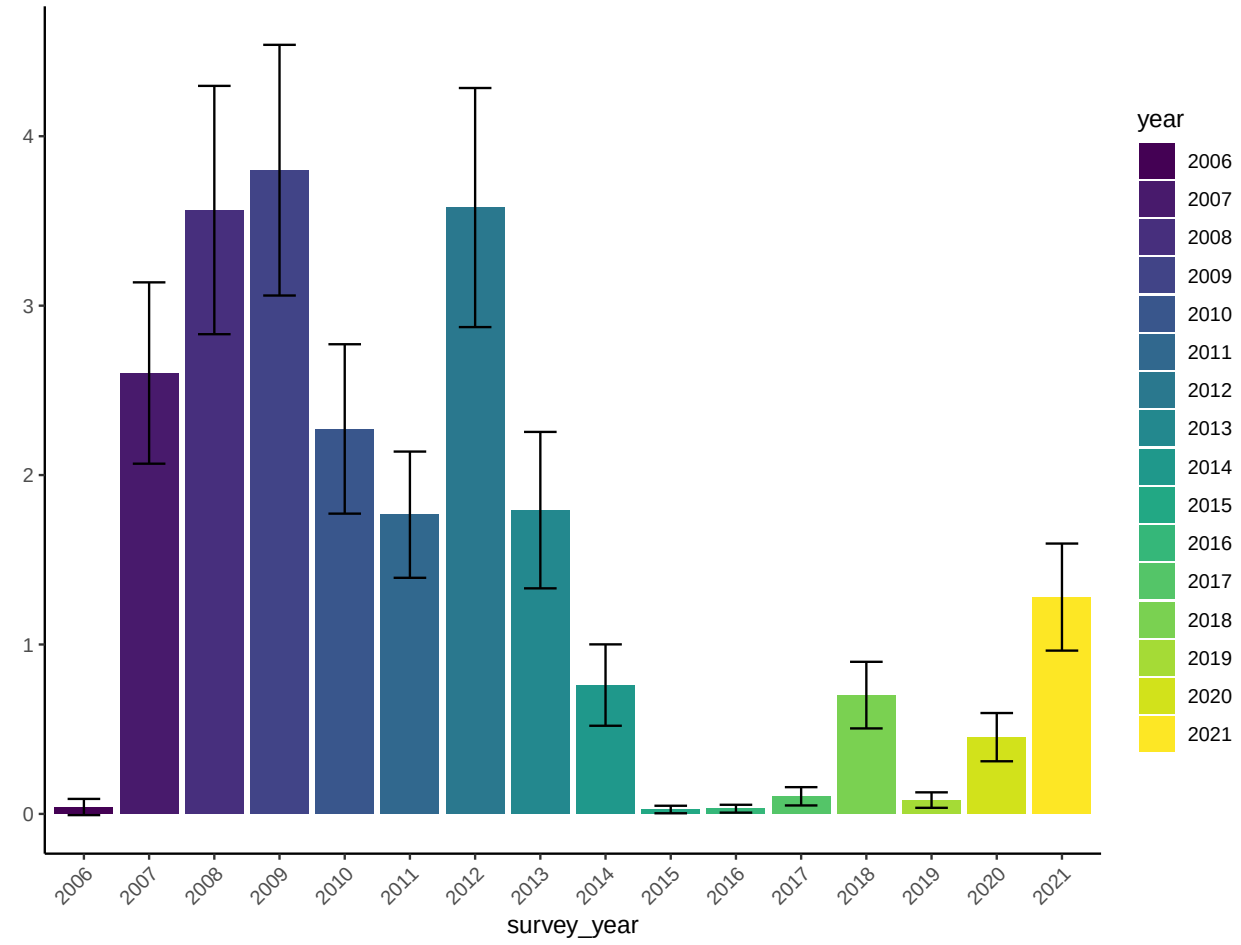
6. Predict to compare to observed

```
testdata <- dat2 %>%
  dplyr::select("log_den_STRPURAD",
                "log_mean_vrm",
                "log_UBR_Max",
                "Max_Monthly_Nitrate",
                "wh_max",
                "log_den_NERLUE",
                "site_name", "zone", "year")

head(testdata)
```

```
##   log_den_STRPURAD log_mean_vrm log_UBR_Max Max_Monthly_Nitrate   wh_max
## 1         4.035223 0.0001370786    5.497168            15.50432 6.918628
## 2         3.044522 0.0001370786    5.497168            15.50432 6.918628
## 3         6.621406 0.0001370786    5.497168            15.50432 6.918628
## 4         4.072309 0.0001370786    5.497168            15.50432 6.918628
## 5         3.828641 0.0001370786    5.497168            15.50432 6.918628
## 6         6.216606 0.0001370786    5.497168            15.50432 6.918628
##   log_den_NERLUE site_name  zone year
## 1              0 Fort Ross OUTER 2015
## 2              0 Fort Ross OUTER 2015
## 3              0 Fort Ross OUTER 2015
## 4              0 Fort Ross INNER 2015
## 5              0 Fort Ross INNER 2015
## 6              0 Fort Ross INNER 2015
```

```
# fit the data
fits <- predict.gam(gam1, newdata = testdata, type = 'response', se.fit = T)


## predict average kelp per year --
predicts.year <- testdata %>%
  data.frame(fits) %>%
  group_by(year) %>% #only change here
  summarise(response=mean(fit, na.rm = T), se.fit = mean(se.fit, na.rm = T))%>%
  ungroup()


ggmod.year <- ggplot(aes(x = year, y = response,fill = year), data = predicts.year) +
  ylab(" ")+
  xlab('survey_year')+
```

```
  scale_fill_viridis(discrete = T) +
  geom_bar(stat = "identity")+
  geom_errorbar(aes(ymin = response - se.fit, ymax = response + se.fit),width = 0.5) +
  theme_classic() +
  theme(axis.text.x = element_text(angle = 45, h = 1))

ggmod.year
```



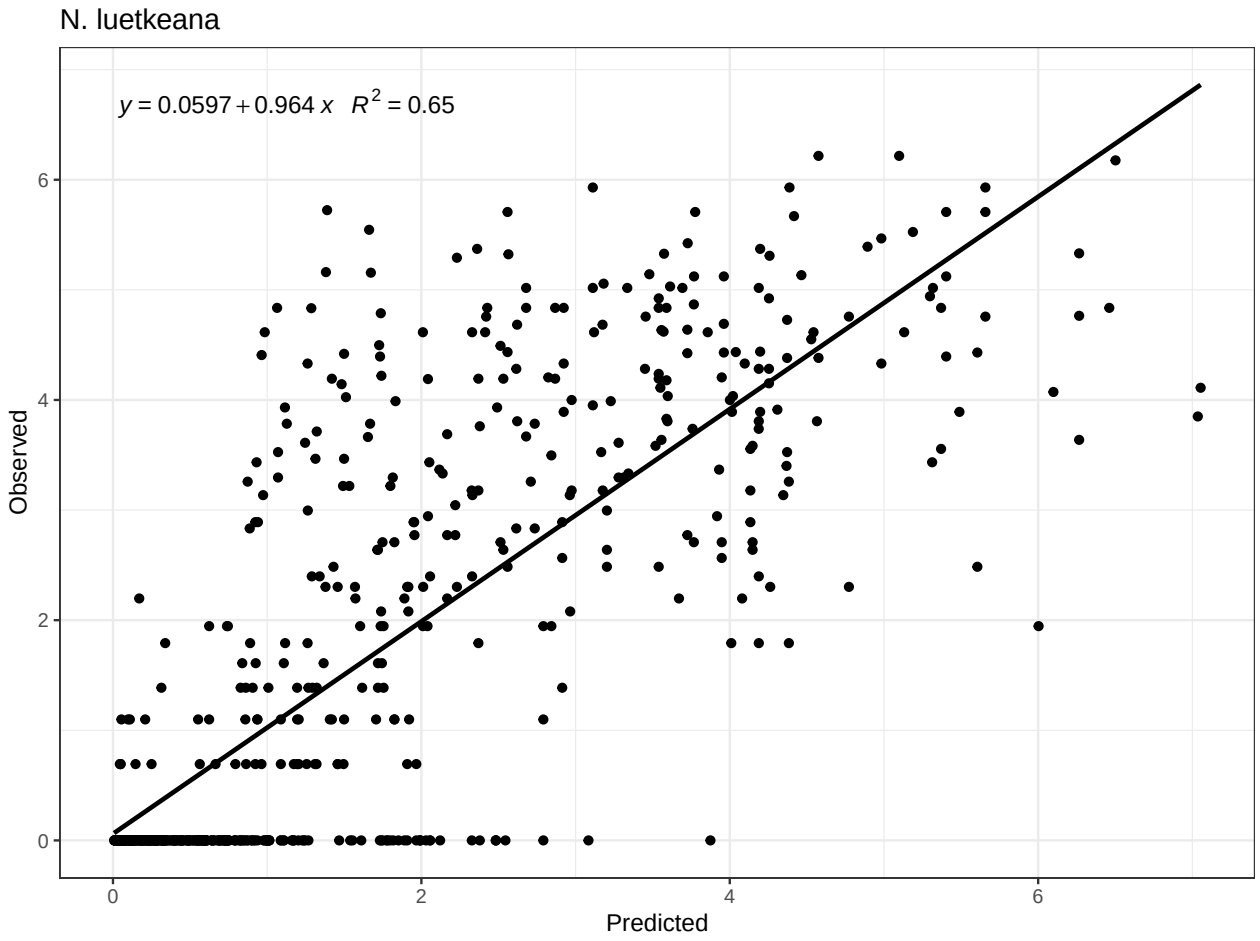
7. Plot observed vs. predicted

```
predicts.all <-  testdata %>%
  data.frame(fits) %>%
  #group_by(survey_year) %>% #only change here
  #summarise(response=mean(fit), se.fit = mean(se.fit)) %>%
  ungroup() %>%
  glimpse()
```

```
## Rows: 686
## Columns: 11
```

```
## $ log_den_STRPURAD    <dbl> 4.0352234, 3.0445224, 6.6214057, 4.0723087, 3.8286~
## $ log_mean_vrm        <dbl> 0.0001370786, 0.0001370786, 0.0001370786, 0.000137~
## $ log_UBR_Max         <dbl> 5.497168, 5.497168, 5.497168, 5.497168, 5.497168, ~
## $ Max_Monthly_Nitrate <dbl> 15.50432, 15.50432, 15.50432, 15.50432, 15.50432, ~
## $ wh_max              <dbl> 6.918628, 6.918628, 6.918628, 6.918628, 6.918628, ~
## $ log_den_NERLUE      <dbl> 0.000000, 0.000000, 0.000000, 0.000000, 0.000000, ~
## $ site_name           <fct> Fort Ross, Fort Ross, Fort Ross, Fort Ross, Fort R~
## $ zone                <fct> OUTER, OUTER, OUTER, INNER, INNER, INNER, OUTER, O~
## $ year                <fct> 2015, 2015, 2015, 2015, 2015, 2015, 2009, 2009, 20~
## $ fit                 <dbl> 0.05530019, 0.06315784, 0.02616223, 0.06386164, 0.~
## $ se.fit              <dbl> 0.04653202, 0.05328178, 0.02219044, 0.05367881, 0.~
```

```
# Plot observed vs. predicted --
library(ggpmisc)

my.formula <- y ~ x

p <- ggplot(predicts.all, aes(x = fit, y = log_den_NERLUE)) +
  geom_smooth(method = "lm", se=FALSE, color="black", formula = my.formula) +
  stat_poly_eq(formula = my.formula,
               aes(label = paste(..eq.label.., ..rr.label.., sep = "~~~")),
               parse = TRUE) +
  geom_point() +
  #scale_color_viridis(discrete = T) +
  labs(x = 'Predicted', y = 'Observed', title = 'N. luetkeana') +
  theme_bw()
p
```



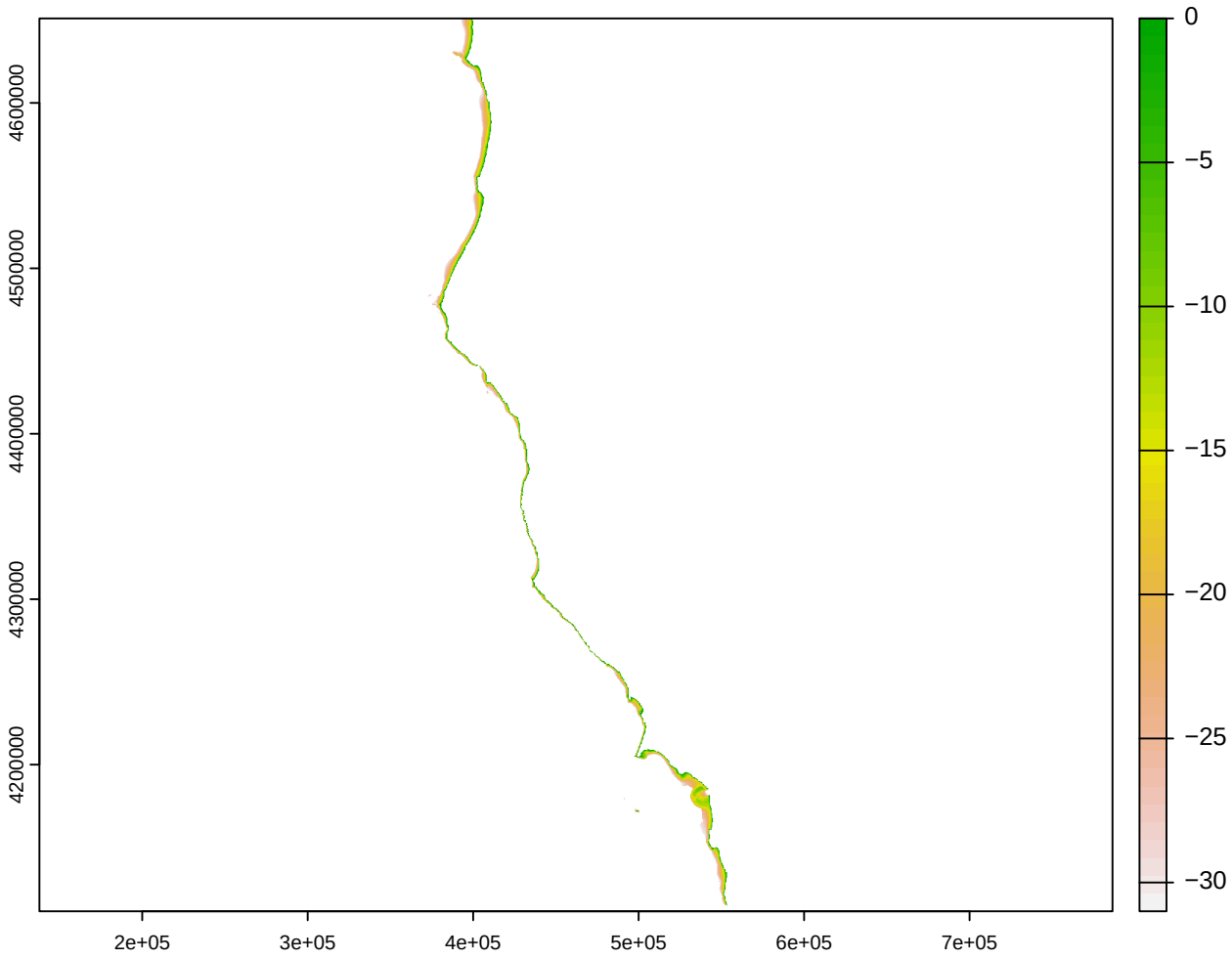
Predict best model across all years and site that I have data for

```
# gam1
# Max_Monthly_Nitrate
# log_UBR_Max
# wh_max
# log_den_STRPURAD

### Get depth ----

depth.dir <- "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/depth"

names(dat2)
```

```
##  [1] "latitude"                      "longitude"
##  [3] "site_name"                     "year"
##  [5] "transect"                      "zone"
##  [7] "Days_10N"                      "Min_Monthly_Nitrate"
##  [9] "Max_Monthly_Nitrate"           "Mean_Monthly_Nitrate"
## [11] "Mean_Monthly_Upwelling_Nitrate" "Max_Monthly_Anomaly_Nitrate"
## [13] "Mean_Monthly_Summer_Nitrate"   "Mean_Monthly_Temp"
## [15] "Mean_Monthly_Summer_Temp"      "MHW_Upwelling_Days"
```

```
## [17] "Min_Monthly_Anomaly_Temp"          "Max_Monthly_Anomaly_Upwelling_Temp"
## [19] "Min_Monthly_Temp"                  "Mean_Monthly_Upwelling_Temp"
## [21] "npgo_mean"                         "mei_mean"
## [23] "mean_depth"                        "mean_prob_of_rock"
## [25] "mean_slope"                        "wh_max"
## [27] "wh_mean"                           "mean_waveyear"
## [29] "wh_95prc"                          "Mean_Monthly_NPP"
## [31] "Max_Monthly_NPP_Upwelling"         "log_den_NERLUE"
## [33] "log_den_MESFRAAD"                  "log_den_STRPURAD"
## [35] "log_den_PYCHEL"                    "log_den_HALRUF"
## [37] "log_mean_vrm"                      "log_Days_16C"
## [39] "log_UBR_Mean"                      "log_UBR_Max"
## [41] "log_Mean_Monthly_NPP_Upwelling"    "log_Min_Monthly_NPP"
```

```
depth <- rast(paste(depth.dir, "depth_mean_nc.all_wInterp_300m_30m.tif", sep ='/'))
plot(depth)
```




```
n.extent <- ext(depth)

crs1 <- "epsg:4326"
d2 <- project(depth, crs1)
```

```
n.extent <- ext(d2)
```

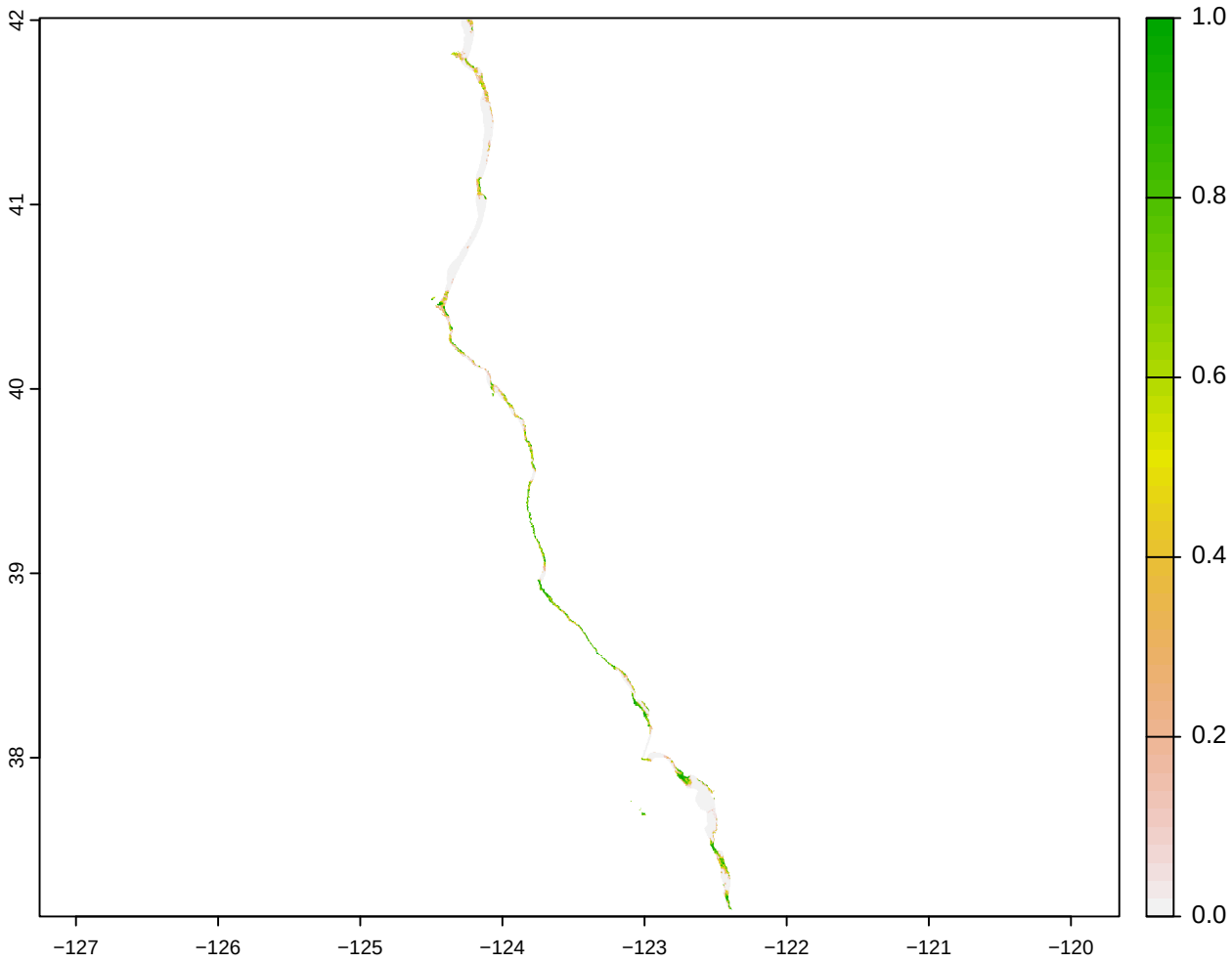
```
## Get rock ----
sub.dir <- "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/rock"

dir(sub.dir)
```

```
## [1] "prob_rock_nc_MASKED_LatLong_all_300m_wInterp.tif"
```

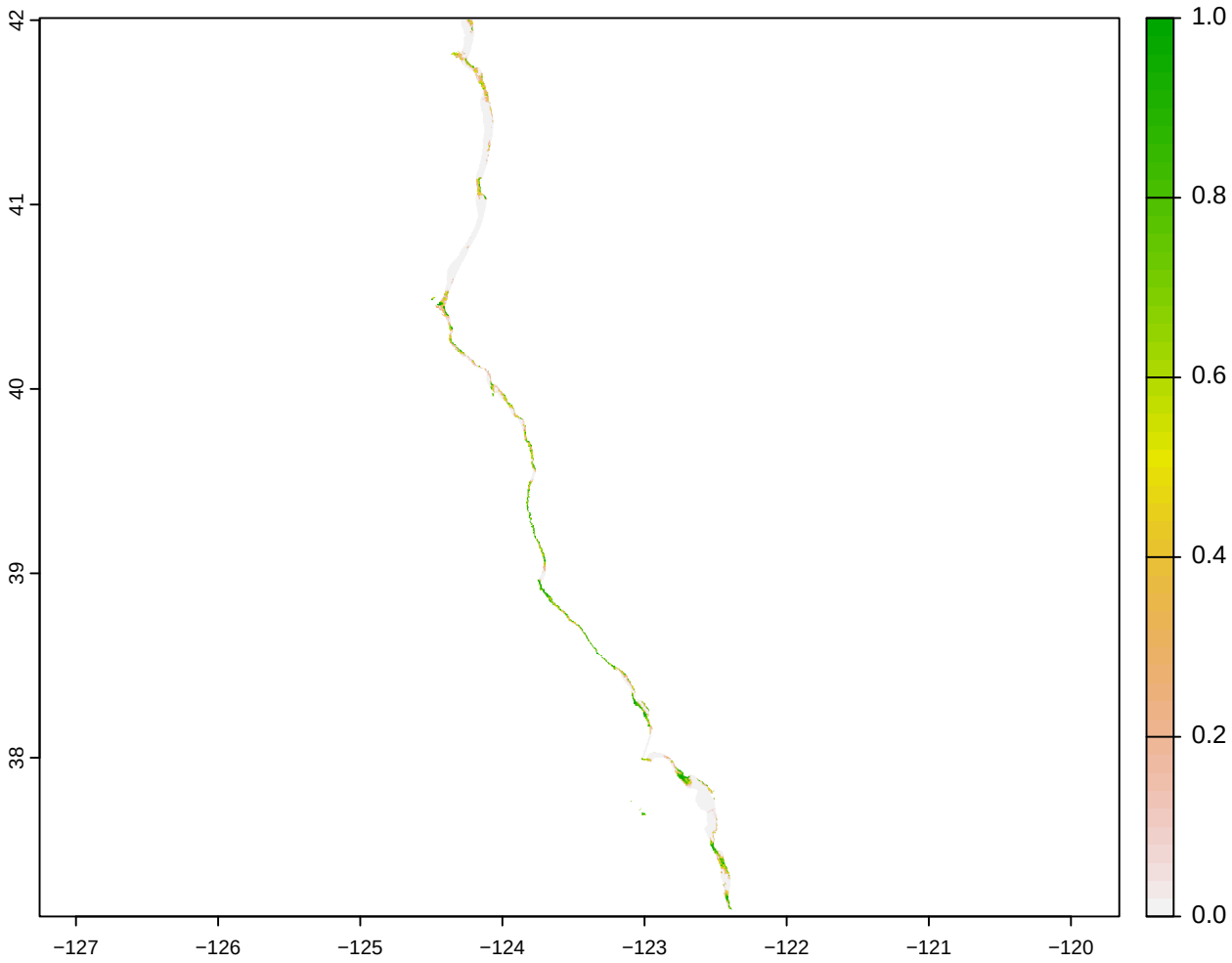
```
rock <- rast(paste(sub.dir, "prob_rock_nc_MASKED_LatLong_all_300m_wInterp.tif", sep ='/'))
rock
```

```
## class       : SpatRaster
## dimensions  : 1740, 799, 1  (nrow, ncol, nlyr)
## resolution  : 0.002800226, 0.002800226  (x, y)
## extent      : -124.5766, -122.3392, 37.13894, 42.01134  (xmin, xmax, ymin, ymax)
## coord. ref. : lon/lat WGS 84 (EPSG:4326)
## source      : prob_rock_nc_MASKED_LatLong_all_300m_wInterp.tif
## name        : prob_rock_nc.all_30m_wInterp
## min value   :                           0
## max value   :                           1
```

```
# crop to NC --
rock2 <- crop(rock, ext(d2))
plot(rock2)
```



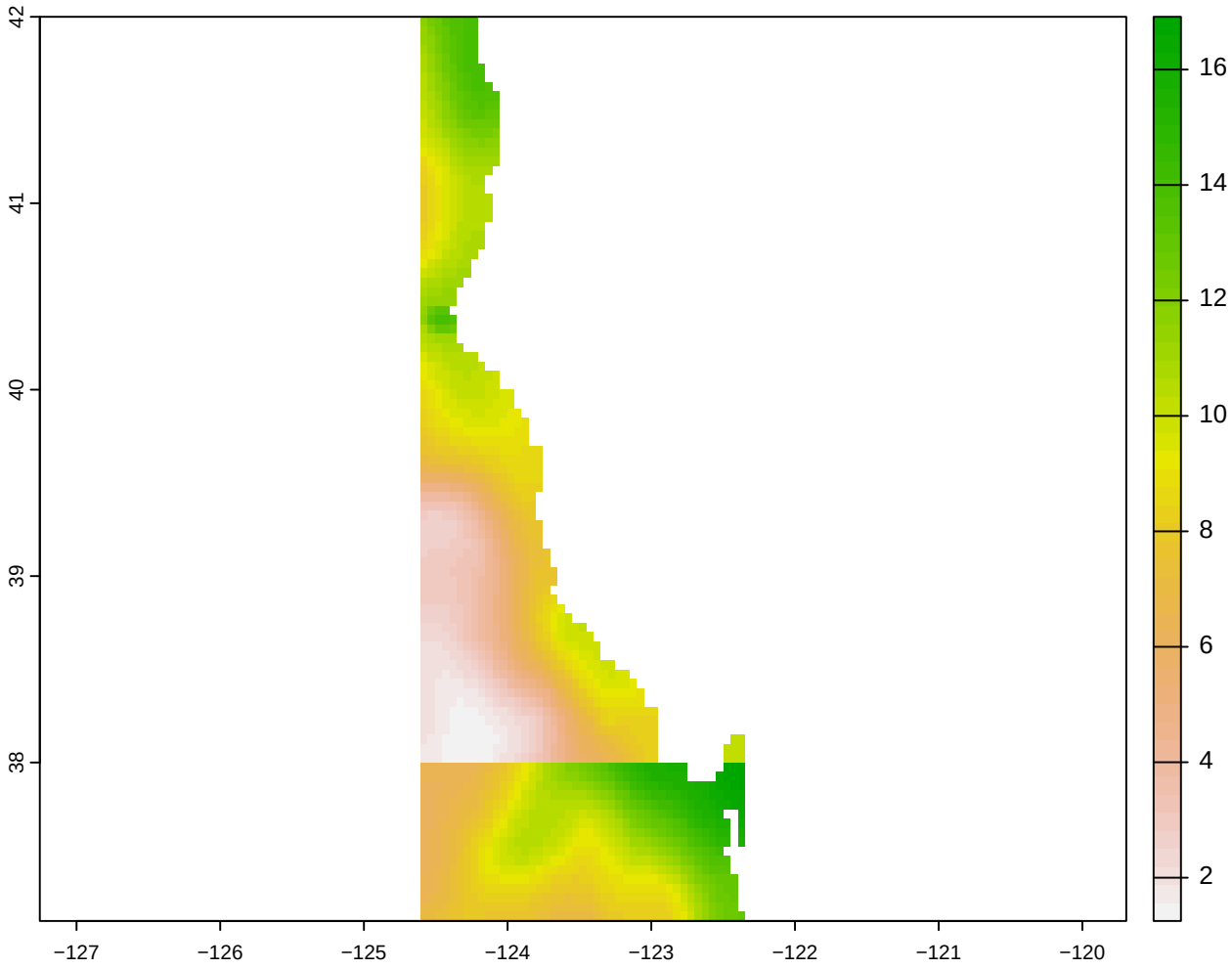

```
rock3 <- resample(rock2, d2)
plot(rock3)
```



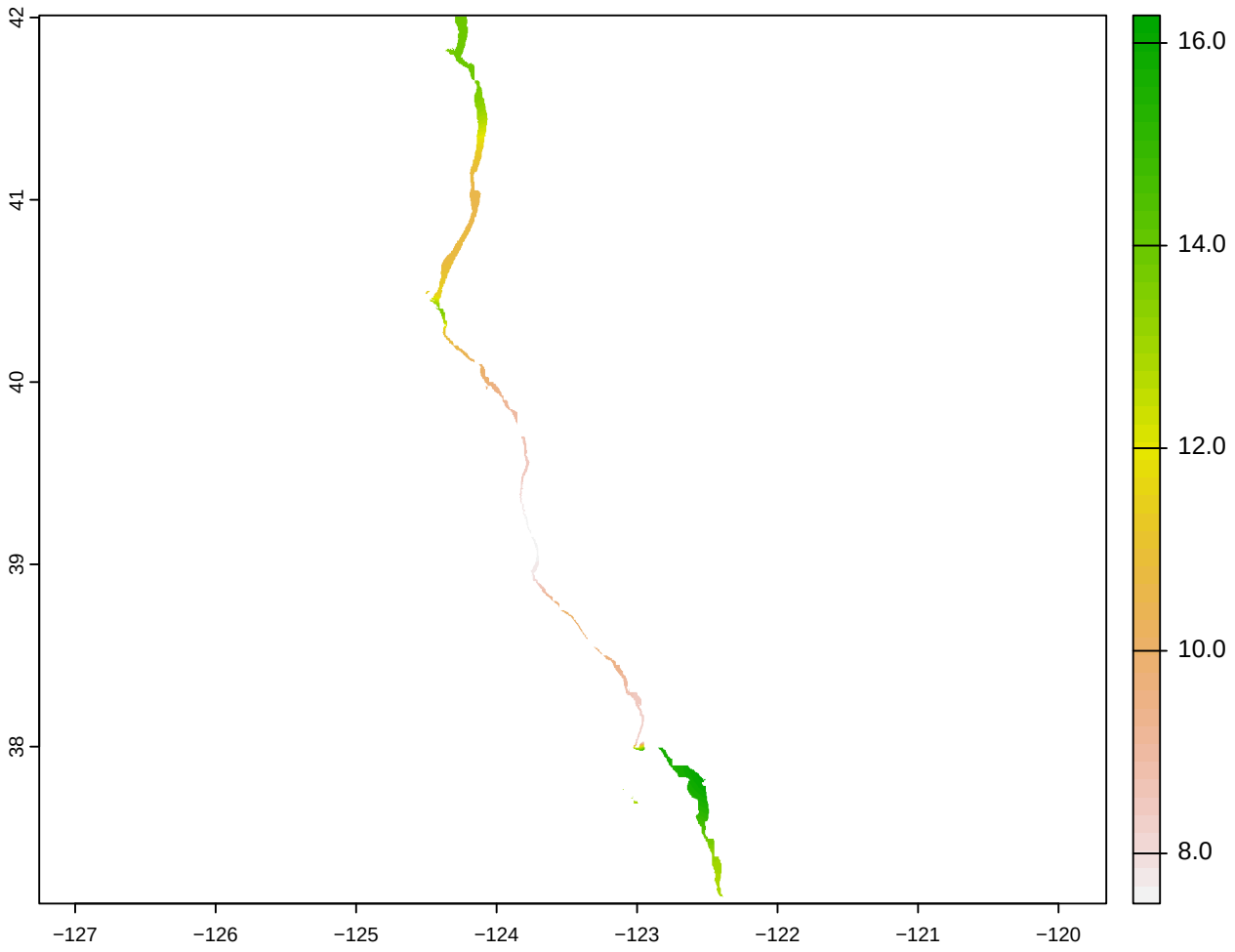

```
### Get Env predictors  ----

re.dir <- "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors"


### Get nitrate predictors  ----
max_nit <- rast(paste(re.dir, "Nitrate", "Max_Monthly_Nitrate.tif", sep ='/'))
max_nit
```

```
## class       : SpatRaster
## dimensions  : 221, 181, 24  (nrow, ncol, nlyr)
## resolution  : 0.05, 0.05  (x, y)
## extent      : -125, -115.95, 32, 43.05  (xmin, xmax, ymin, ymax)
## coord. ref. : lon/lat WGS 84 (EPSG:4326)
## source      : Max_Monthly_Nitrate.tif
## names       : Max_M~ate_1, Max_M~ate_2, Max_M~ate_3, Max_M~ate_4, Max_M~ate_5, Max_M~ate_6, ...
```

```
# # crop to NC --
max_nit2 <- crop(max_nit, n.extent)
plot(max_nit2[[1]])
```




```
# resample predictors to bathy ----
max_nit3 <- resample(max_nit2, d2)

# mask predictors to bathy ----
max_nit4 <- mask(max_nit3, d2)
plot(max_nit4[[1]])
```




```
### Get Wave predictors  ----

w.dir <- "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors"

## Max Wave height --

# load raster data --

wave.dir <- paste(w.dir, "waves", "wh_max", sep ='/')

# load raster data --

n.files <- dir(wave.dir)
# list files in source --
n.files <- list.files(wave.dir, pattern = '.tif$', full.names = TRUE)
n.files
```

```
##  [1] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2004.ti
##  [2] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2005.ti
##  [3] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2006.ti
##  [4] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2007.ti
##  [5] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2008.ti
```

```
##  [6] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2009.ti
##  [7] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2010.ti
##  [8] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2011.ti
##  [9] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2012.ti
## [10] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2013.ti
## [11] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2014.ti
## [12] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2015.ti
## [13] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2016.ti
## [14] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2017.ti
## [15] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2018.ti
## [16] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2019.ti
## [17] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2020.ti
## [18] "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/waves/wh_max/wh_max_2021.ti
```

```
length(n.files)
```

```
## [1] 18
```

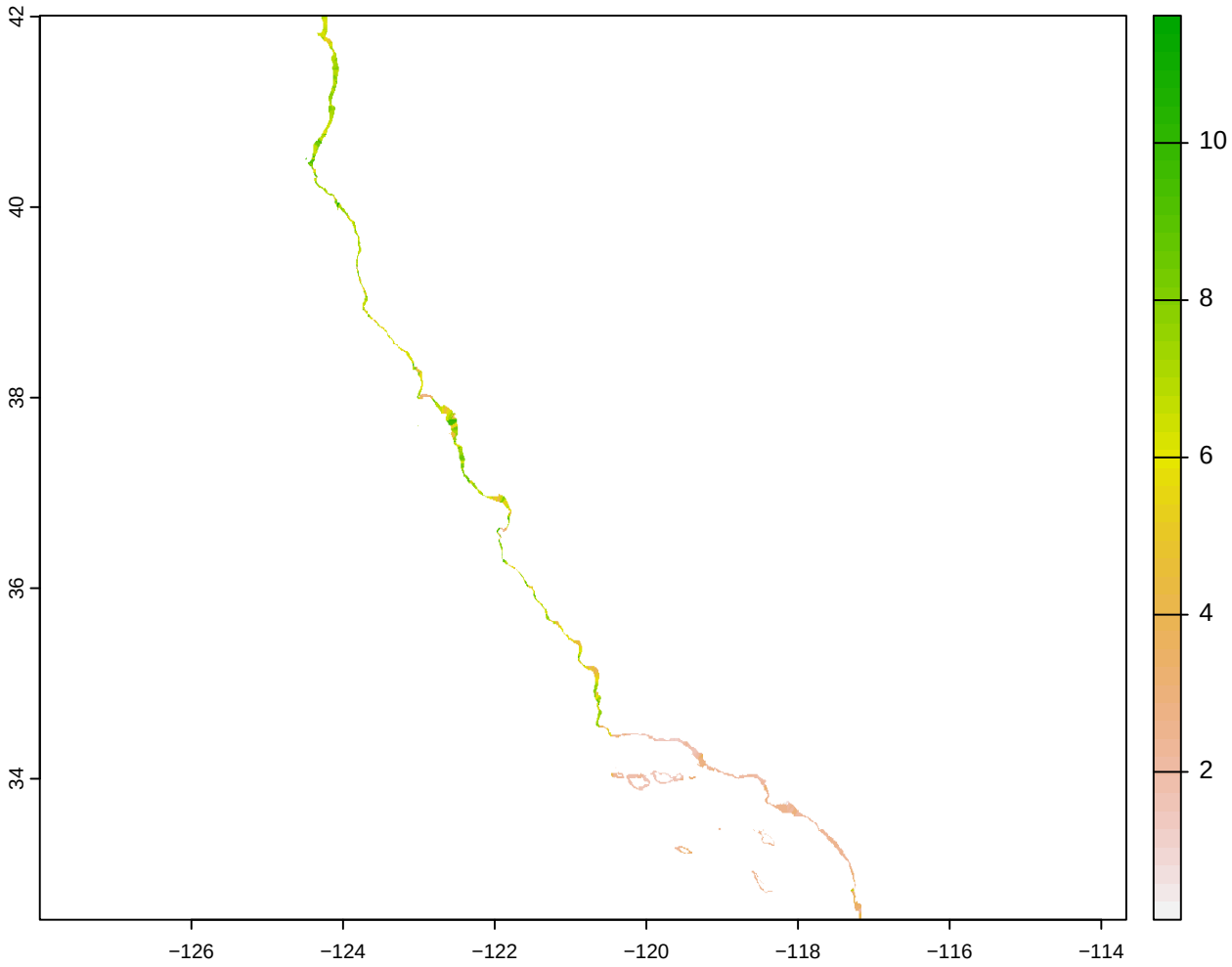
```
# list names to load onto the Environment --
names.list <- list.files(wave.dir, pattern = '.tif$')
names.list <- str_replace(names.list, ".tif$", "")
length(names.list)
```

```
## [1] 18
```

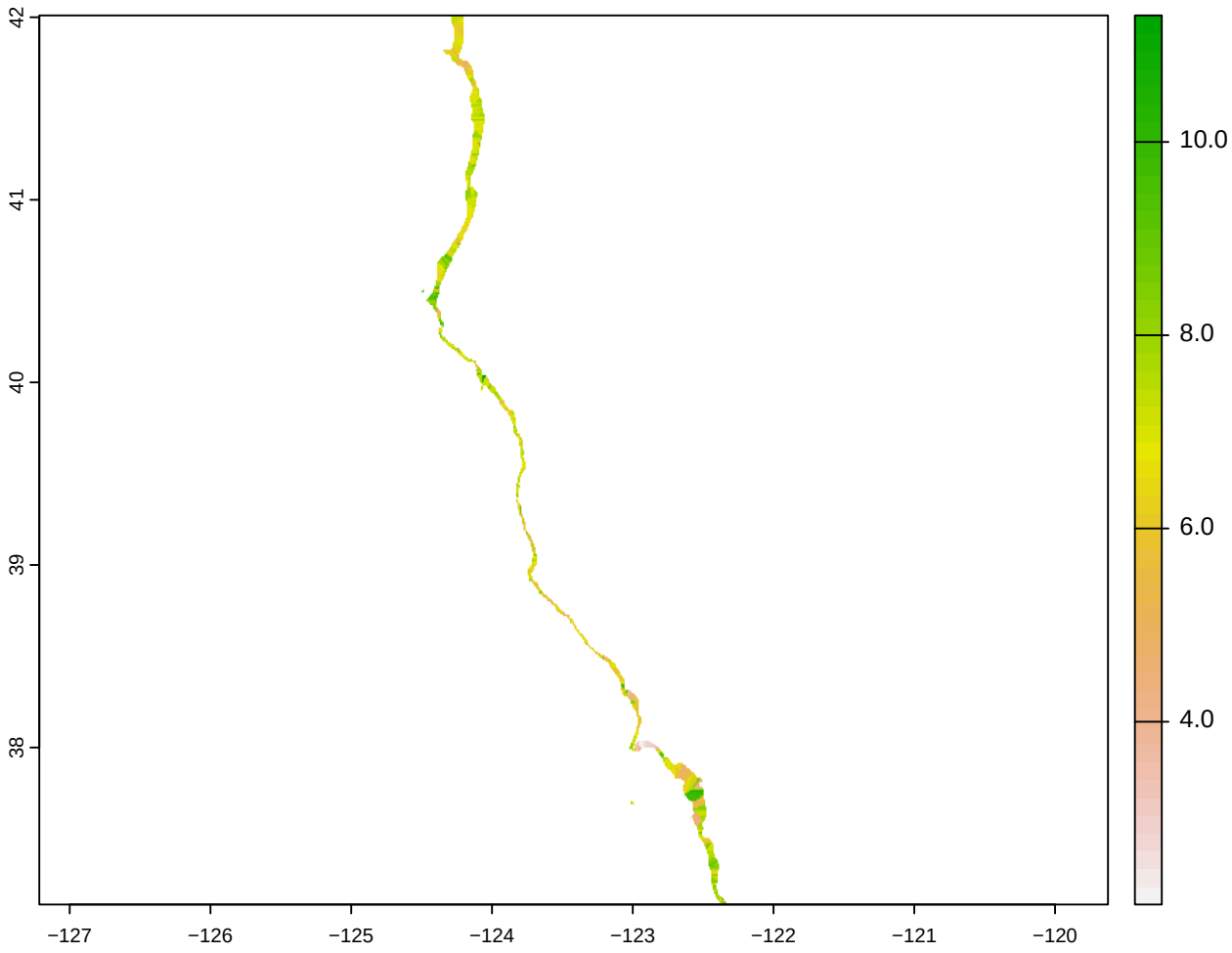
```
# load csv files as a list --
tfiles <- lapply(n.files, rast) # this is a list
tfiles[[1]]
```

```
## class       : SpatRaster
## dimensions  : 949, 733, 1  (nrow, ncol, nlyr)
## resolution  : 0.01, 0.01  (x, y)
## extent      : -124.5, -117.17, 32.52, 42.01  (xmin, xmax, ymin, ymax)
## coord. ref. : lon/lat WGS 84 (EPSG:4326)
## source      : wh_max_2004.tif
## name        : wh_max_2004
## min value   :   0.1193736
## max value   :    11.61992
```

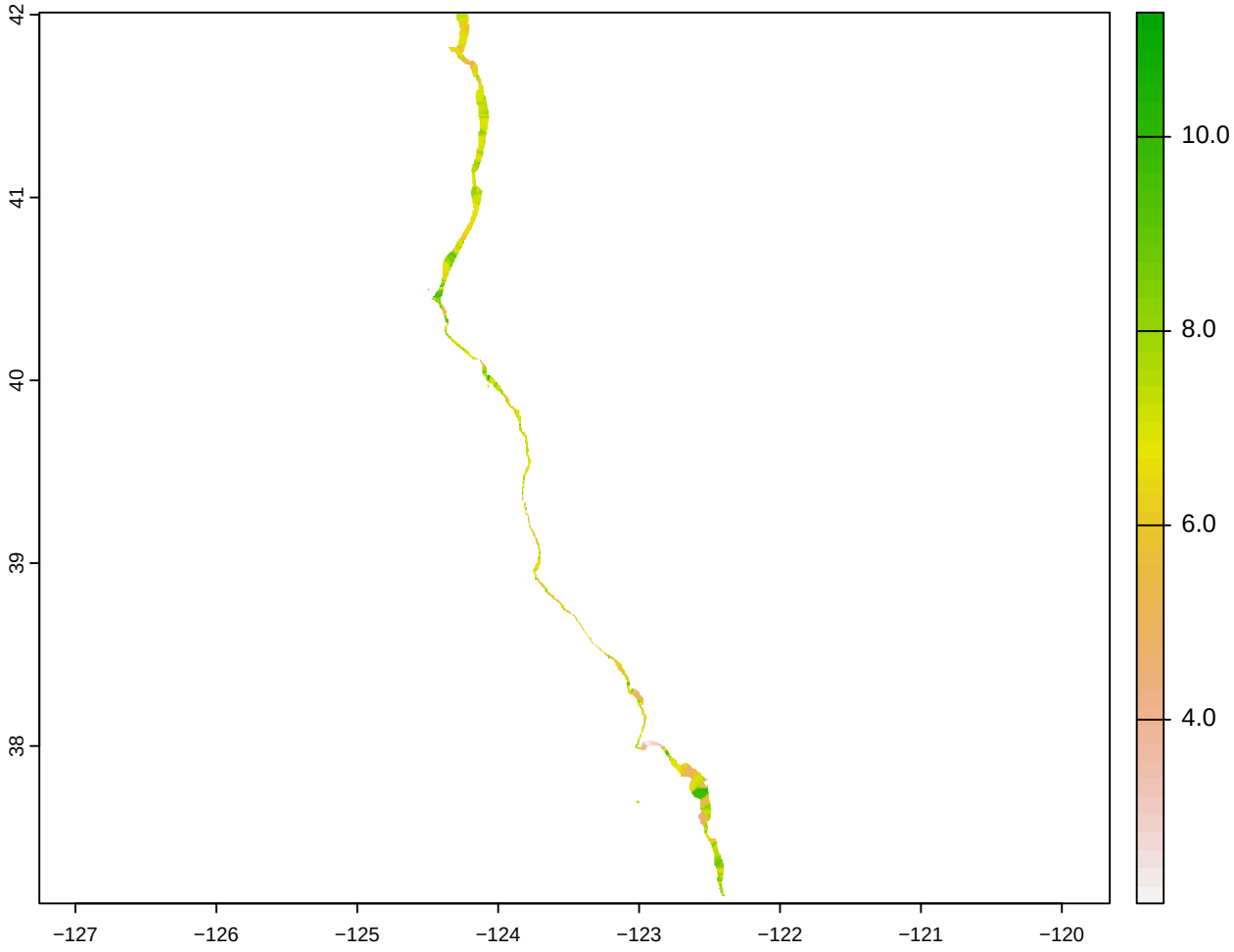
```
# stack them ---
whmax.stack <- c()

# use do call to create a raster otherwise it creates a list
whmax.stack <- do.call("c", tfiles)
plot(whmax.stack[[1]])
```



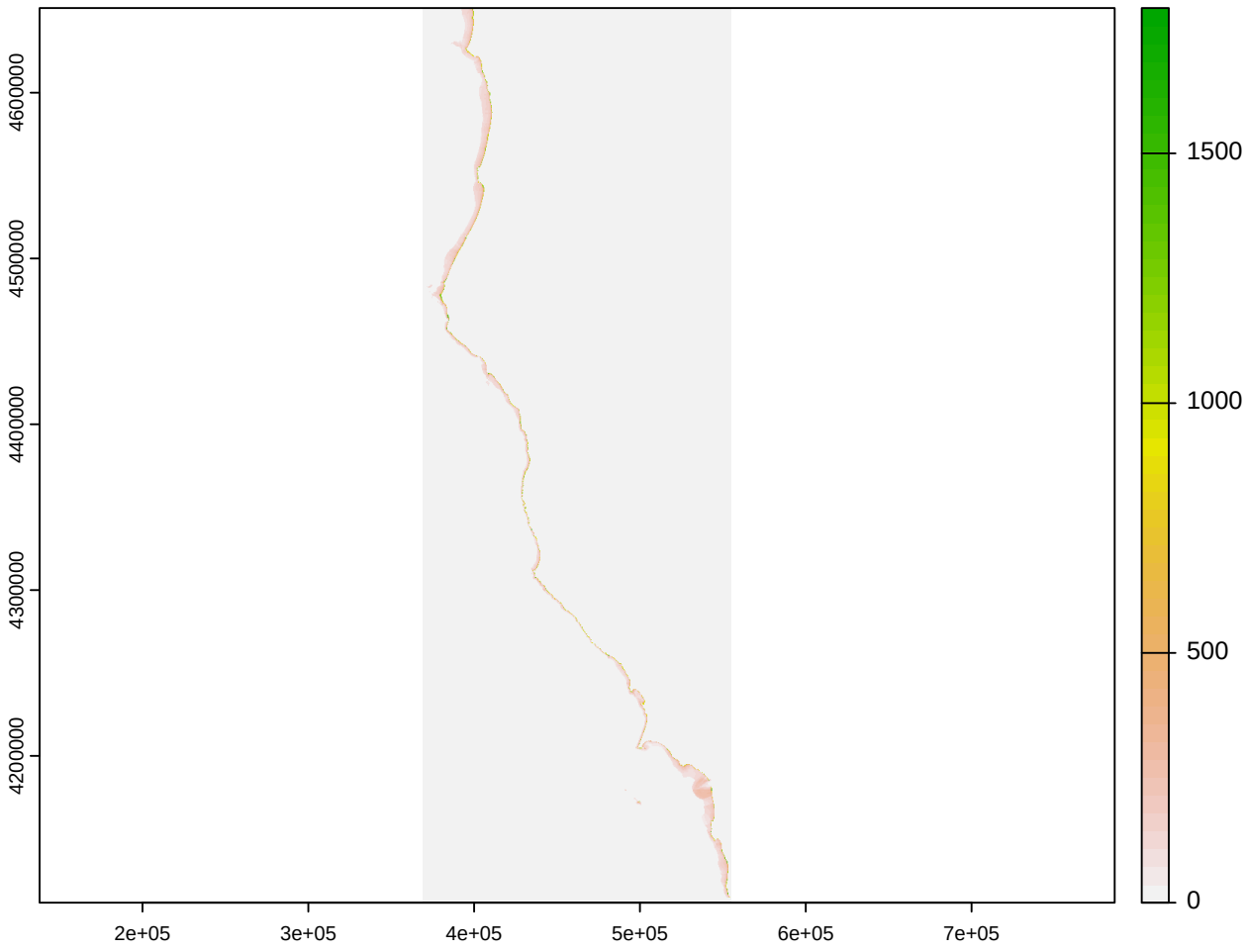

```
# # crop to NC --
whmax.stack2 <- crop(whmax.stack, n.extent)
plot(whmax.stack2[[1]])
```



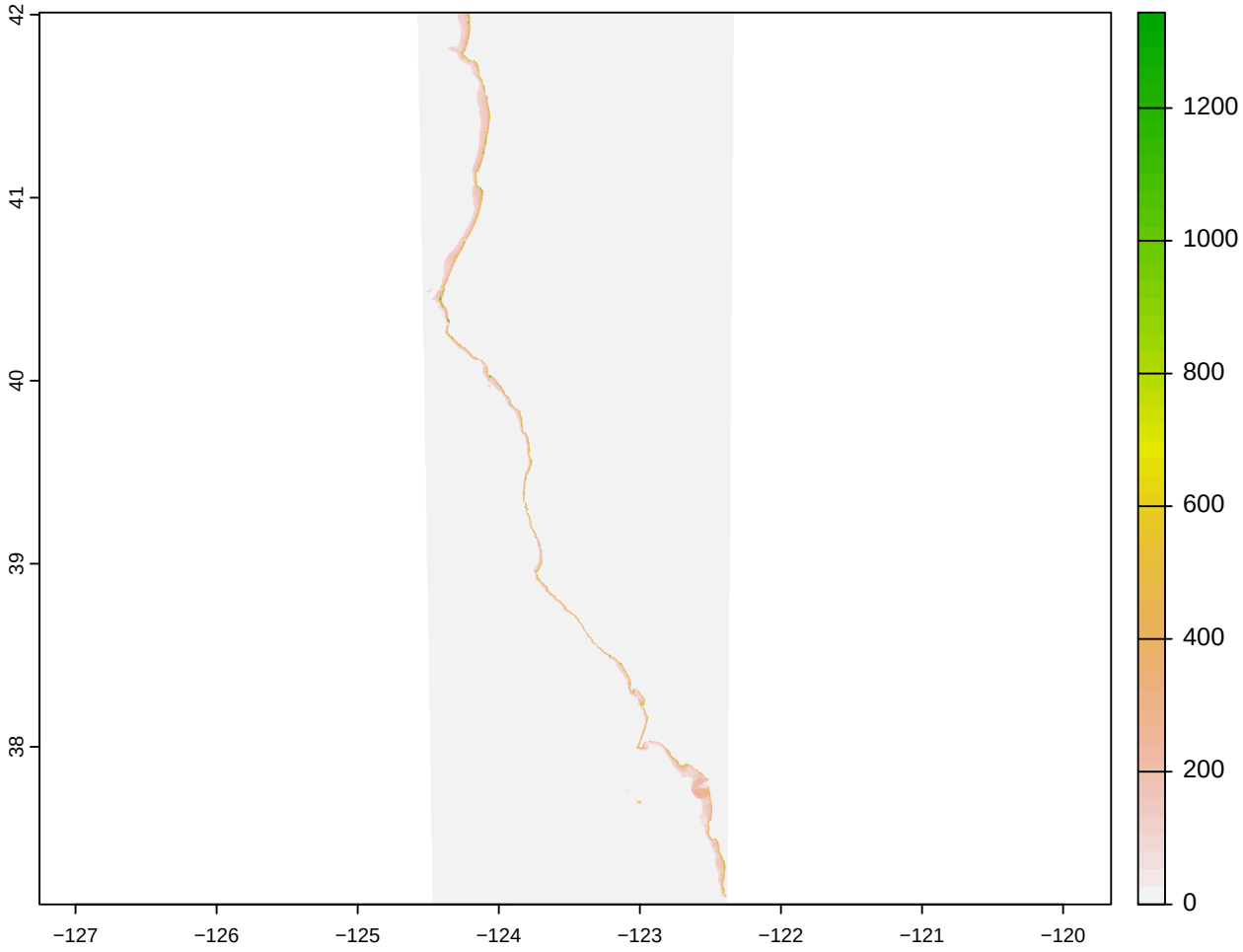

```
# resample predictors to bathy ----
whmax.stack3 <- resample(whmax.stack2, d2)

# mask predictors to bathy ----
whmax.stack4 <- mask(whmax.stack3, d2)
plot(whmax.stack4[[1]])
```



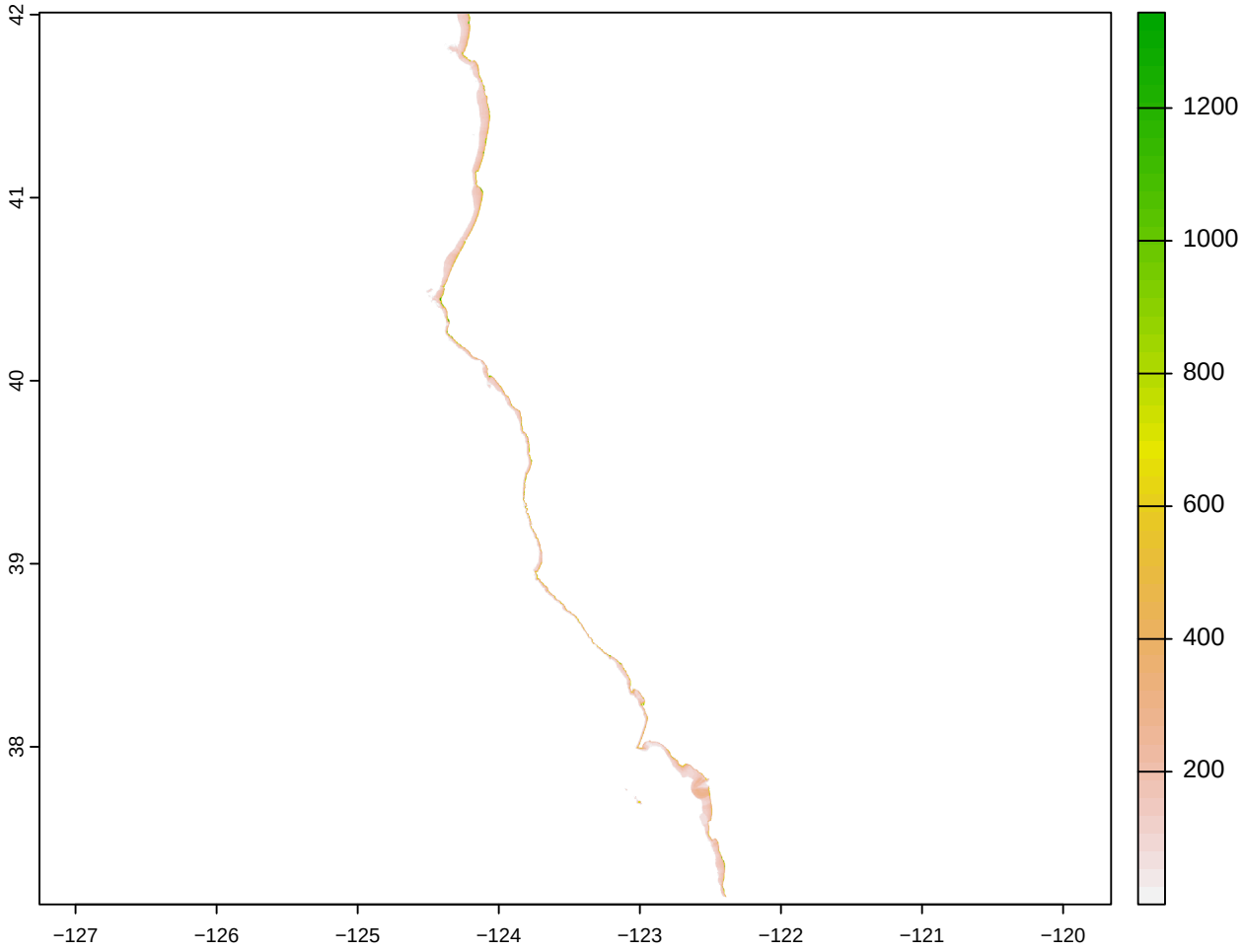

```
## Mean UBR MAX ----

w2.dir <- "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/orbital_vel"

# load raster data --

ubr <- rast(paste(w2.dir, "UBR_Max_30m_NC.tif", sep ='/'))
plot(ubr[[1]])
```



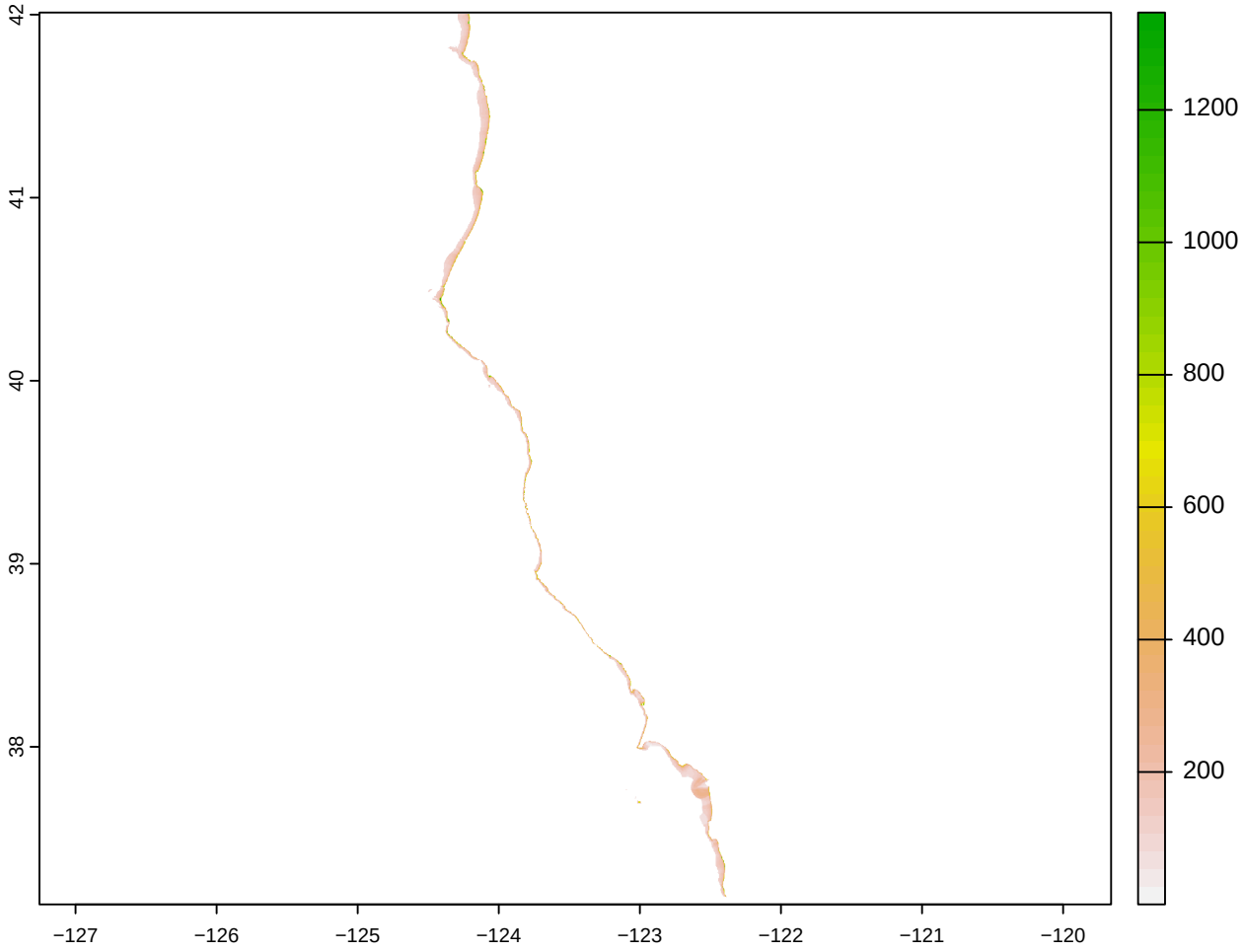

```
ubr <- project(ubr, rock)

plot(ubr[[1]])
```




```
ubr1 <- classify(ubr, cbind(0, NA))
plot(ubr1[[1]])
```




```
# # crop to NC --
ubr2 <- crop(ubr1, n.extent)
plot(ubr2[[1]])

# resample predictors to bathy ----
ubr3 <- resample(ubr2, d2)

# mask predictors to bathy ----
ubr4 <- mask(ubr3, d2)
plot(ubr4[[1]])
```




```
ubr5 <- log(ubr4)
```

```
### Get urchins ----

# load purple urchin predictions ----
urch.dir <- "/Volumes/GoogleDrive/My Drive/SURE_Project/Spatial_data/Predictors/urchins/log_sp_predicti

# load raster data --

u.files <- dir(urch.dir)
u.files <- list.files(urch.dir, pattern = '.tif')
u.files
```

```
##  [1] "2004_log_purple_urchins_NC_V3.tif" "2005_log_purple_urchins_NC_V3.tif"
##  [3] "2006_log_purple_urchins_NC_V3.tif" "2007_log_purple_urchins_NC_V3.tif"
##  [5] "2008_log_purple_urchins_NC_V3.tif" "2009_log_purple_urchins_NC_V3.tif"
##  [7] "2010_log_purple_urchins_NC_V3.tif" "2011_log_purple_urchins_NC_V3.tif"
##  [9] "2012_log_purple_urchins_NC_V3.tif" "2013_log_purple_urchins_NC_V3.tif"
## [11] "2014_log_purple_urchins_NC_V3.tif" "2015_log_purple_urchins_NC_V3.tif"
## [13] "2016_log_purple_urchins_NC_V3.tif" "2017_log_purple_urchins_NC_V3.tif"
## [15] "2018_log_purple_urchins_NC_V3.tif" "2019_log_purple_urchins_NC_V3.tif"
## [17] "2020_log_purple_urchins_NC_V3.tif" "2021_log_purple_urchins_NC_V3.tif"
```

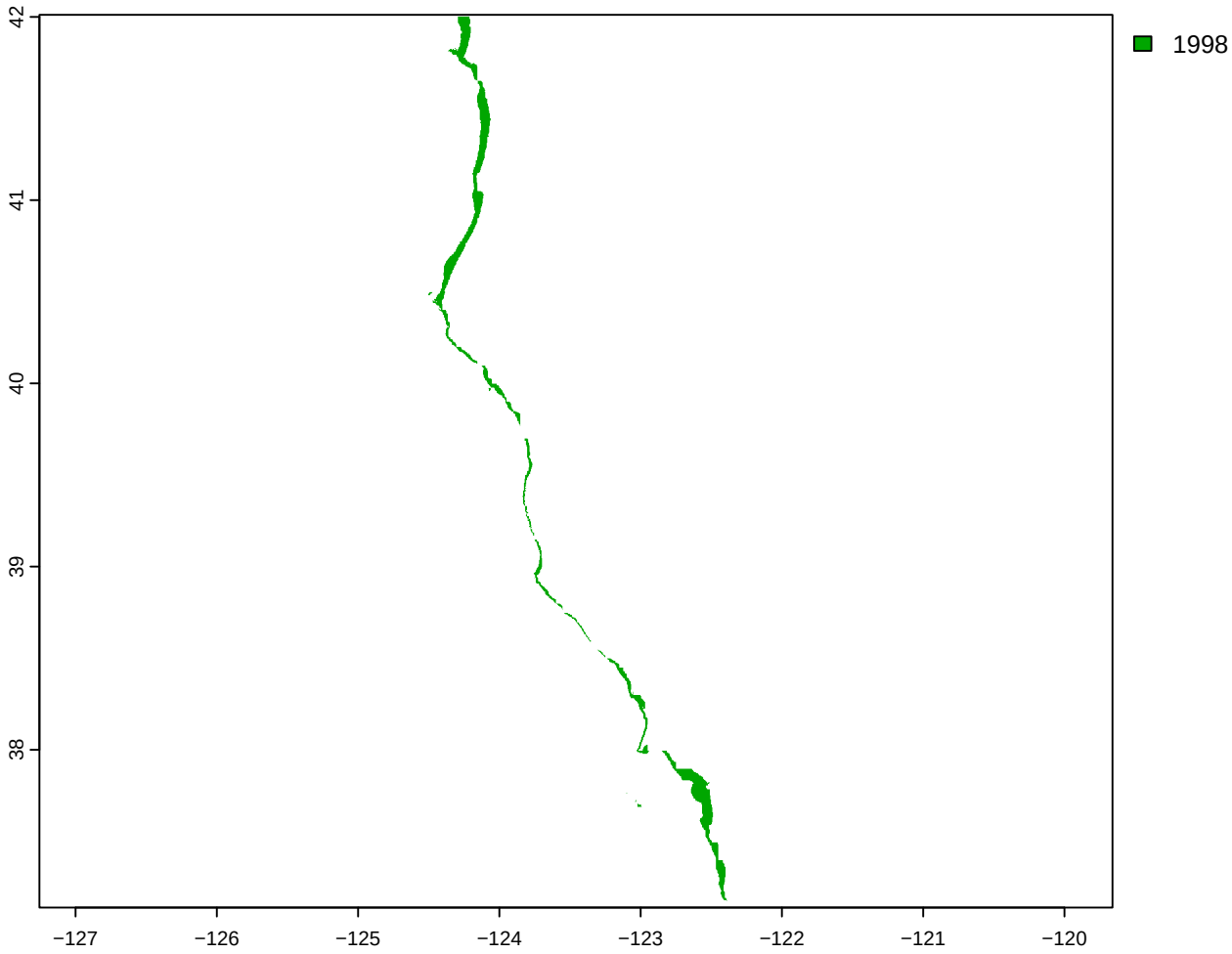
```
length(u.files)
```

```
## [1] 18
```

```
##

# stack rasters --

preds1 <- c(max_nit4[[1]], whmax.stack4[[1]], ubr5[[1]])
names(preds1)
```

```
## [1] "Max_Monthly_Nitrate_1" "wh_max_2004"           "UBR_Max_30m_NC_1"
```

```
# get year raster ----

year1998 <- classify(max_nit4[[1]], cbind(0, Inf, 1998), right=FALSE)
plot(year1998)
```



```
names(year1998) <- 'year'

year.list <- paste(1998:2021)
length(year.list)
```

```
## [1] 24
```

```
preds2 <- c(preds1, year1998)
names(preds2)
```

```
## [1] "Max_Monthly_Nitrate_1" "wh_max_2004"           "UBR_Max_30m_NC_1"
## [4] "year"
```

```
names(preds2) <- c("Max_Monthly_Nitrate" ,
                   "wh_max",
                   "log_UBR_Max",
                   "year")
```

```
# sites ----

rdf <- as.data.frame(year1998, xy = T)
head(rdf)
```

```
##              x        y year
## 3298 -124.2924 41.99884 1998
## 3299 -124.2896 41.99884 1998
## 3300 -124.2868 41.99884 1998
## 3301 -124.2840 41.99884 1998
## 3302 -124.2812 41.99884 1998
## 3303 -124.2784 41.99884 1998
```

```
rdf$site <- rdf$y
rdf <- rdf[,-3]
head(rdf)
```

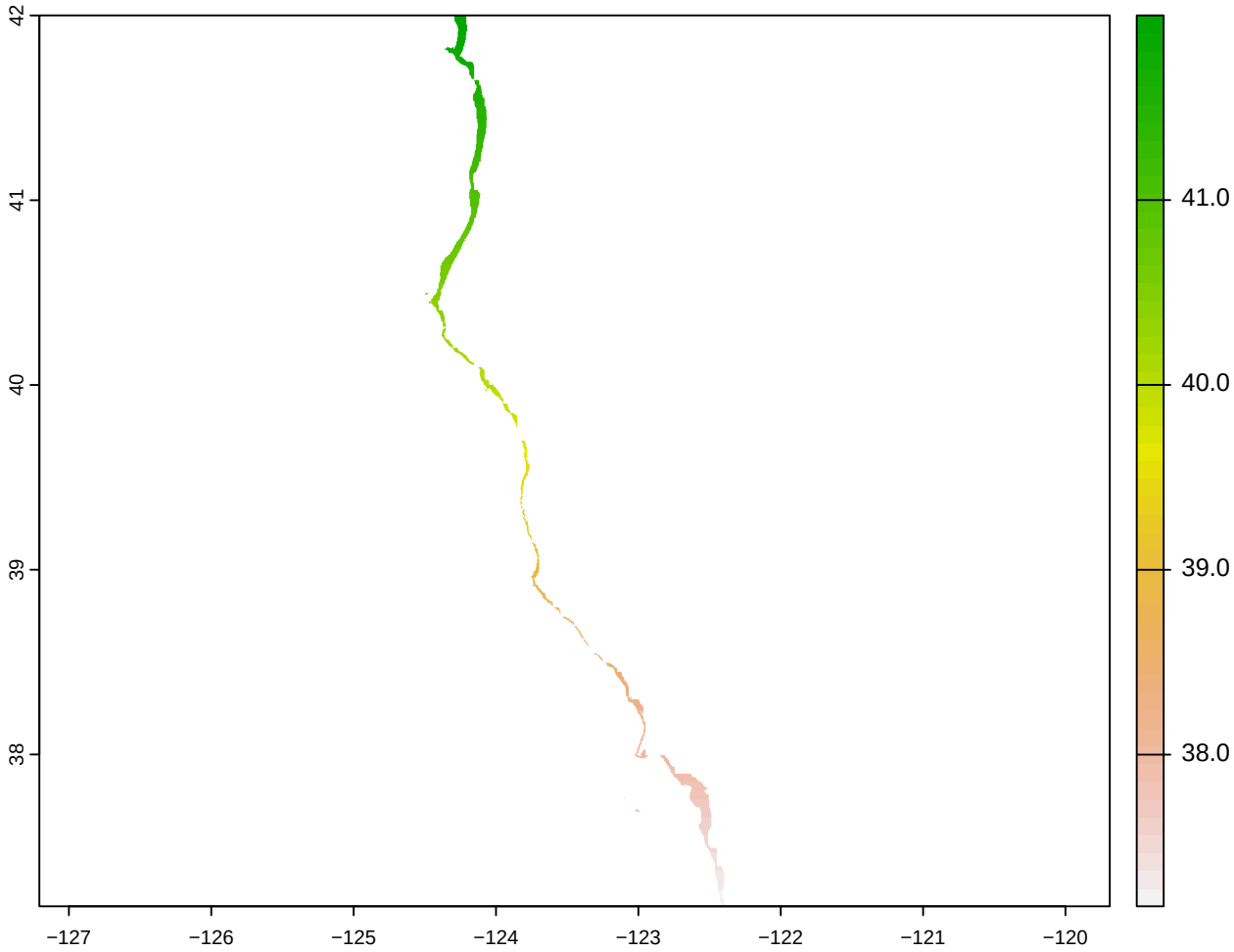
```
##              x        y     site
## 3298 -124.2924 41.99884 41.99884
## 3299 -124.2896 41.99884 41.99884
## 3300 -124.2868 41.99884 41.99884
## 3301 -124.2840 41.99884 41.99884
## 3302 -124.2812 41.99884 41.99884
## 3303 -124.2784 41.99884 41.99884
```

```
site.raster <- rast(rdf, type = 'xyz', crs="EPSG:4326", extent = ext(year1998))
site.raster
```

```
## class       : SpatRaster
## dimensions  : 1722, 754, 1  (nrow, ncol, nlyr)
## resolution  : 0.002800227, 0.002800227  (x, y)
## extent      : -124.5038, -122.3924, 37.17825, 42.00024  (xmin, xmax, ymin, ymax)
```

```
## coord. ref. : lon/lat WGS 84 (EPSG:4326)
## source      : memory
## name        :     site
## min value   : 37.17965
## max value   : 41.99884
```

```
plot(site.raster)
```




```
ext(year1998)
```

```
## SpatExtent : -124.57660297128, -122.339221801492, 37.1390505044726, 42.0114450419344 (xmin, xmax, ym
```

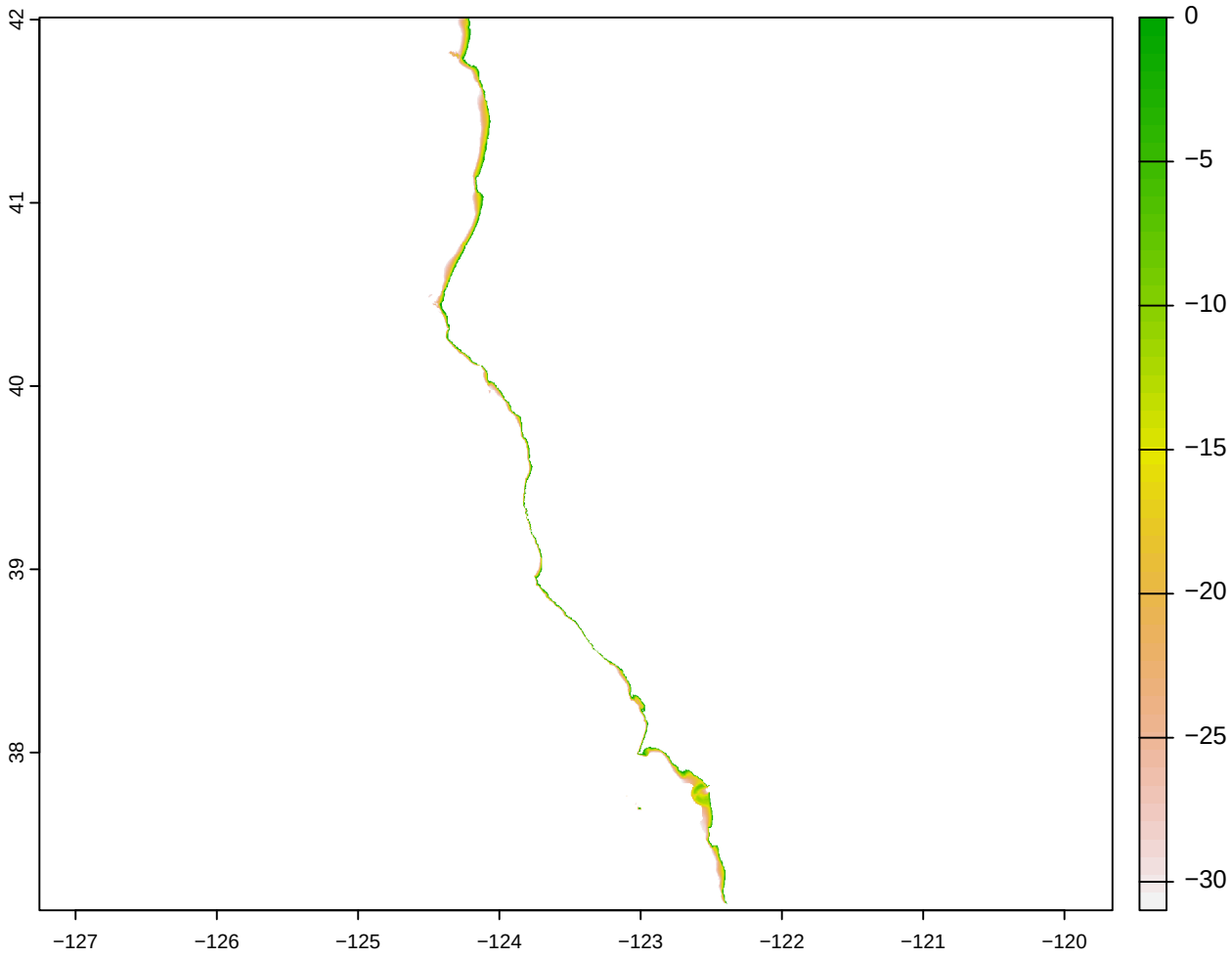
```
ext(site.raster)
```

```
## SpatExtent : -124.50379708, -122.39242611, 37.17825368, 42.00024413 (xmin, xmax, ymin, ymax)
```

```
site.raster2 <- extend(site.raster, year1998)

preds3 <- c(preds2, site.raster2)
```

```
names(preds3) <- c("Max_Monthly_Nitrate"  ,
                   "wh_max",
                   "log_UBR_Max",
                   "year" ,
                   "site_name")
```

```
# zone ----

zone.raster <- d2
names(zone.raster) <- 'zone'
plot(zone.raster)
```

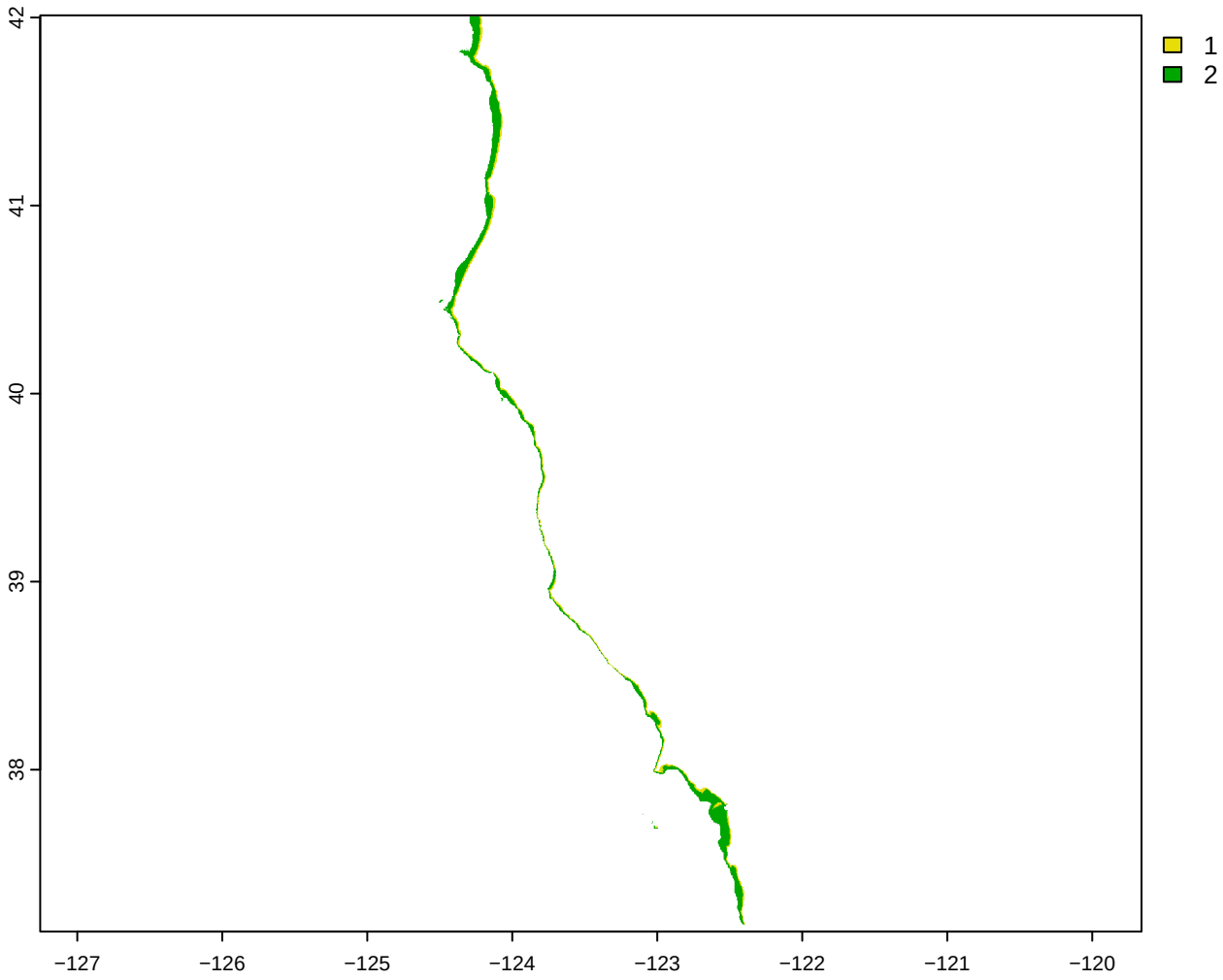



```
levels(dat2$zone)
```

```
## [1] "INNER" "OUTER"
```

```
rec.m <-  c(-Inf, -10, 2,
            -10, 0.1, 1)
```

```
rclmat <- matrix(rec.m, ncol=3, byrow=TRUE)

zone.raster2 <- classify(zone.raster, rclmat, right=FALSE)
plot(zone.raster2)
```




```
preds4 <- c(preds3, zone.raster2)
names(preds4)
```

```
## [1] "Max_Monthly_Nitrate" "wh_max"              "log_UBR_Max"
## [4] "year"                "site_name"           "zone"
```

```
names(preds4) <- c("Max_Monthly_Nitrate" ,
                   "wh_max",
                   "log_UBR_Max",
                   "year",
                   "site_name",
                   "zone")
```

LOOP to predict each year using data frame

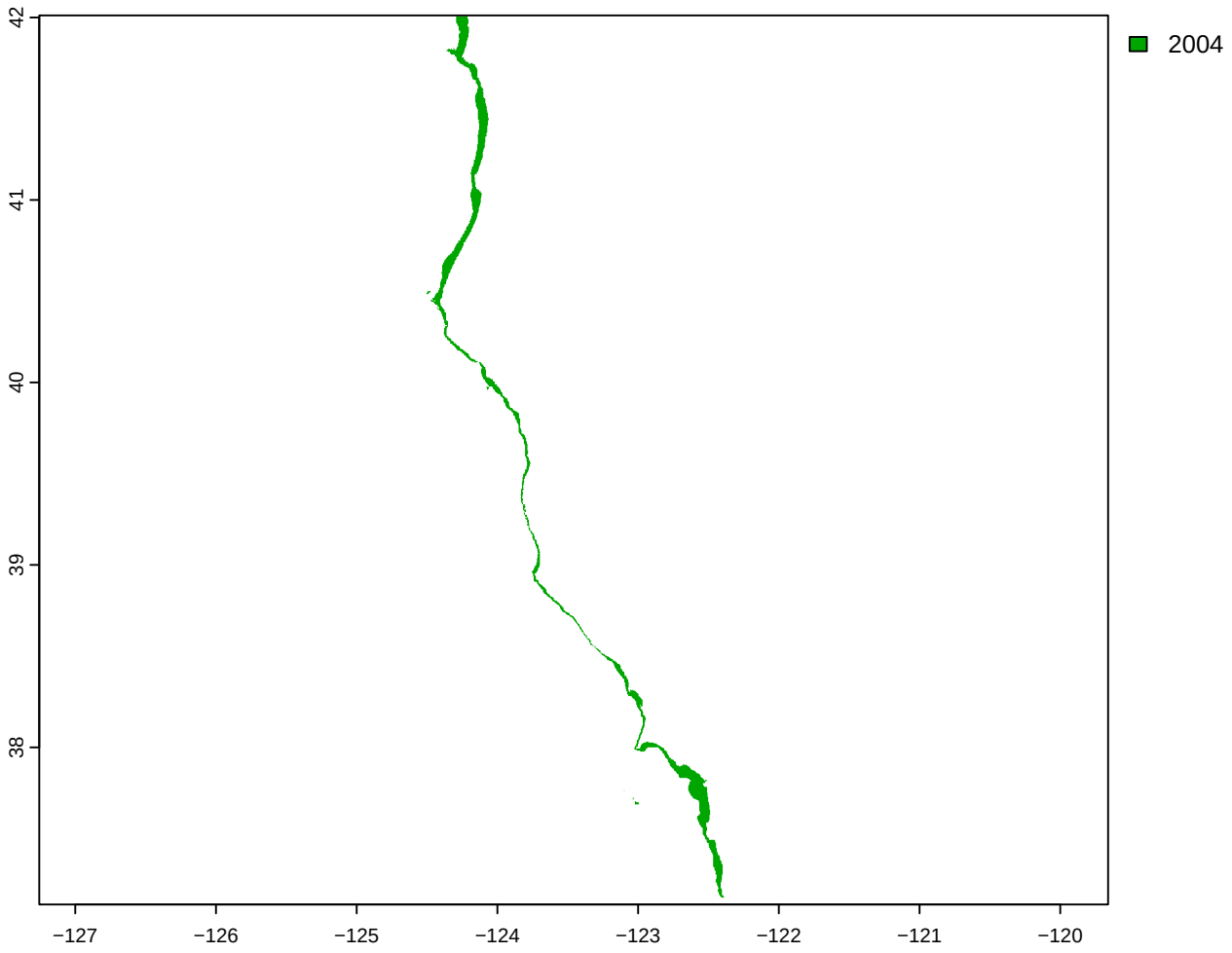
```
nereo.mod <- gam1
summary(nereo.mod)
```

```
##
## Family: Tweedie(p=1.085)
## Link function: log
##
## Formula:
## log_den_NERLUE ~ s(log_den_STRPURAD, k = 5, bs = "cr") + s(Max_Monthly_Nitrate,
##     k = 5, bs = "cr") + s(wh_max, k = 5, bs = "cr") + s(log_UBR_Max,
##     k = 4, bs = "cr") + s(site_name, zone, bs = "re") + s(year,
##     bs = "re")
##
## Parametric coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept)  -0.5254     0.3789  -1.387    0.166
##
## Approximate significance of smooth terms:
##                            edf Ref.df      F  p-value
## s(log_den_STRPURAD)      2.358  2.680  8.543 6.17e-05 ***
## s(Max_Monthly_Nitrate)   3.294  3.651 11.159  < 2e-16 ***
## s(wh_max)                3.698  3.918 10.613  < 2e-16 ***
## s(log_UBR_Max)           2.667  2.884  7.611 0.000286 ***
## s(site_name,zone)       15.335 19.000  4.033 2.31e-05 ***
## s(year)                 12.784 15.000  9.229  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.623   Deviance explained = 64.5%
## -REML = 880.45  Scale est. = 1.3074    n = 686
```

```
# make list of years --
year.list <- paste(2004:2021)
length(year.list)
```

```
## [1] 18
```

```
# make template raster of year ----
year.raster <- classify(d2, cbind(-Inf, 0.1, 2004), right=FALSE)
plot(year.raster)
```




```
names(year.raster) <- 'year'

# make zone raster ----

# outputs dir ----
# * use an output directory of yours
o2.dir <- here('spatial_data')

preds.dir <- paste(o2.dir, "preds", sep ='/')
preds.dir
```

```
## [1] "/Users/chuntingzheng/Desktop/Git_Repositories/Chunting_Spatial_Analyses/spatial_data/preds"
```

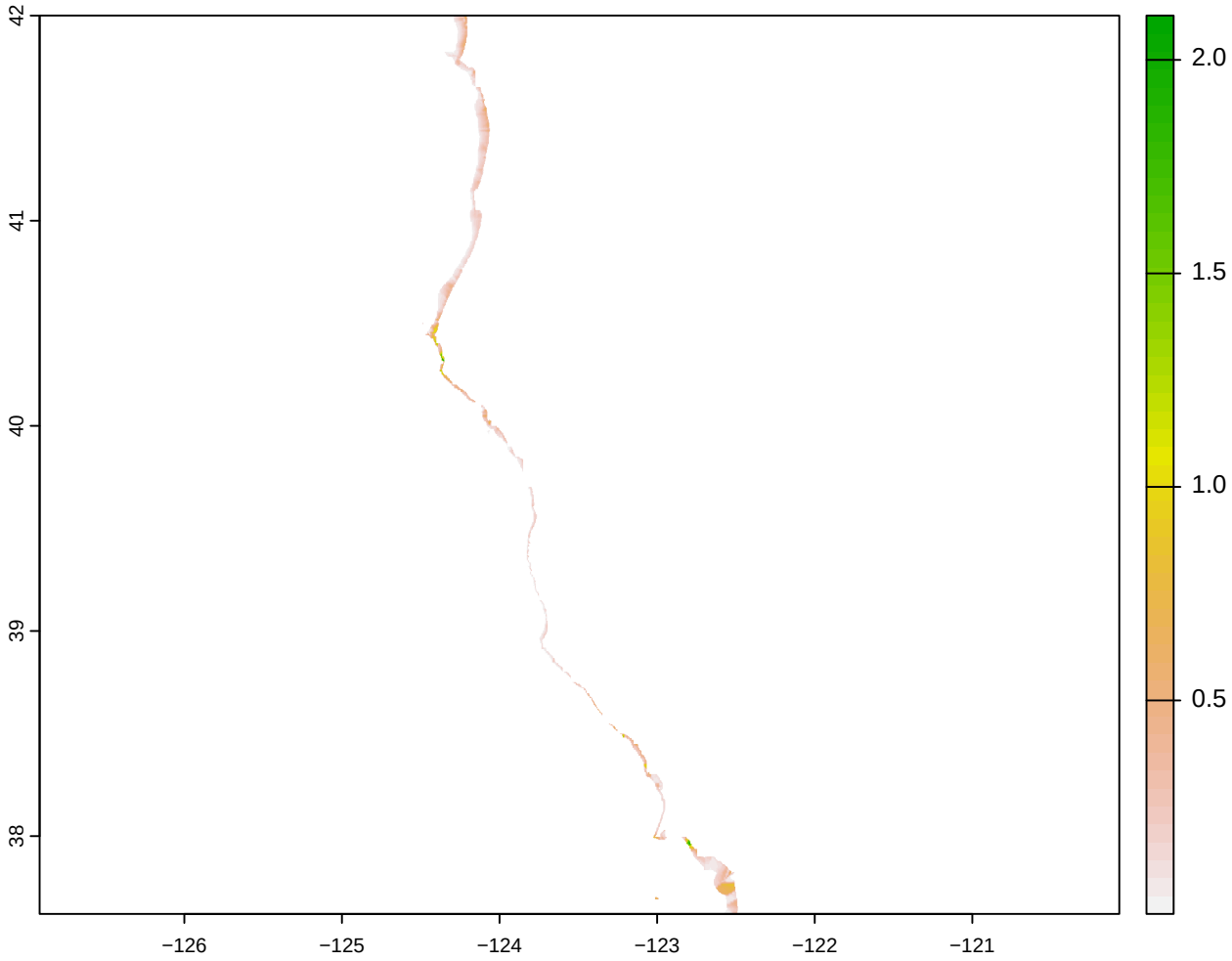
```
# output for rasters scaled by rock
# * use an output directory of yours
rock.preds.dir <- paste(o2.dir, "rock_preds", sep ='/')
rock.preds.dir
```

```
## [1] "/Users/chuntingzheng/Desktop/Git_Repositories/Chunting_Spatial_Analyses/spatial_data/rock_preds
```

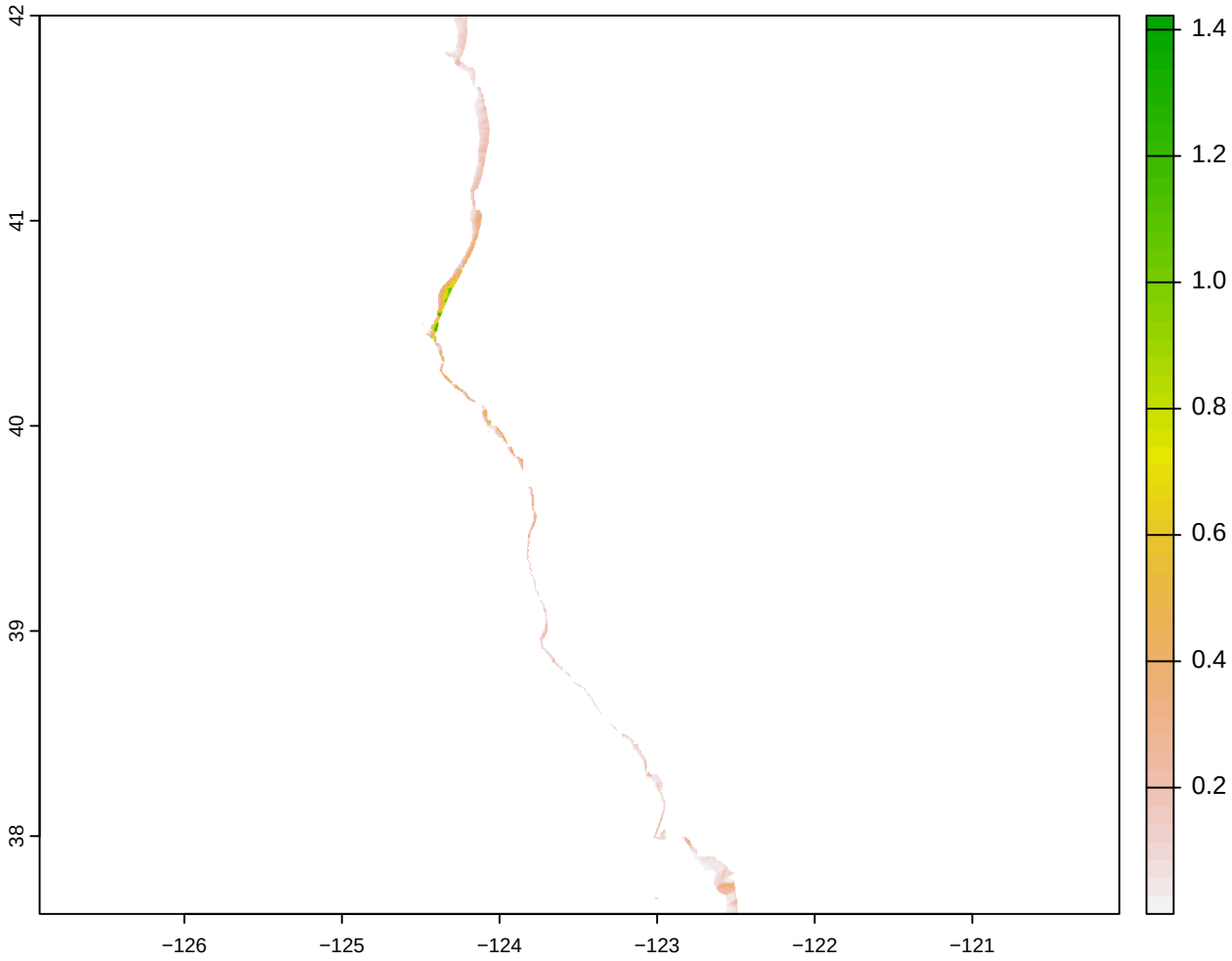
```
for (i in 1:length(year.list)) {

  # 1. get urchins
  urchin.rast <- rast(paste(urch.dir, u.files[i], sep ='/'))
  urchin.rast2 <- resample(urchin.rast, d2)

  # 2. stack with predictors for that year
  #env.raster <- c(d2, max_nit4[[i+6]], whmax.stack4[[i]], wymean.stack4[[i]])

  #env.raster <- c(d2, mean_up_T4[[i+6]], max_nit4[[i+6]], whmax.stack4[[i]], wymean.stack4[[i]])

  # V3
  env.raster <- c(max_nit4[[i+6]], whmax.stack4[[i]], ubr5[[i]])

  preds1 <- c(urchin.rast2, env.raster)

  # 3. get year and stack it
  year.no <- as.numeric(year.list[i])
  year.r <- classify(year.raster, cbind(-Inf, 0, year.no), right=FALSE)

  preds2 <- c(preds1, year.r)

  # 3. stack zone
  preds3 <- c(preds2, zone.raster2)

  # 4. stack site
  preds4 <- c(preds3, site.raster2)

  # name predictors
  names(preds4) <- c("log_den_STRPURAD",
                     "Max_Monthly_Nitrate"  ,
                     "wh_max",
                     "log_UBR_Max",
                     "year",
                     "zone",
                     "site_name")

  df4 <- as.data.frame(preds4, xy = T) %>%
    mutate_at(vars(year, zone, site_name), list(as.factor)) %>%
    mutate(zone = recode_factor(zone, '1' = 'INNER', '2' = 'OUTER')) %>%
    glimpse()

  # 5. predict
  year.pred.df <- predict.gam(nereo.mod, newdata = df4, type = 'response', se.fit = T)
  head(year.pred.df)

  # join with df for lats and lons
  preds.all <-  df4 %>%
    data.frame(year.pred.df) %>%
    dplyr::select(x, y, fit) %>%
    glimpse()

  # 6. Rasterize
```

```
  crs.p <- "epsg:4326"
  year.prediction <- rast(preds.all, type = 'xyz', crs = crs.p, digits = 6)
  plot(year.prediction)

  # 7. save raw raster
  # name.raster <- paste(year.no, "Log_Nereo_GIVE_IT_A_NAME.tif", sep = '_')
  name.raster <- paste(year.no, "Log_Nereo_NC.tif", sep = '_')
  writeRaster(year.prediction, paste(preds.dir, name.raster, sep = '/'))

  # 8. scale by rock
  rock4 <- resample(rock3, year.prediction)
  year.prediction2 <- rock4*year.prediction

  # 9. save rastr scaled by rock
  # name.raster.rock <- paste(year.no, "Log_Nereo_rock__GIVE_IT_A_NAME.tif", sep = '_')
  name.raster.rock <- paste(year.no, "Log_Nereo_rock_NC.tif", sep = '_')
  writeRaster(year.prediction2, paste(rock.preds.dir, name.raster.rock, sep = '/'))
}
```

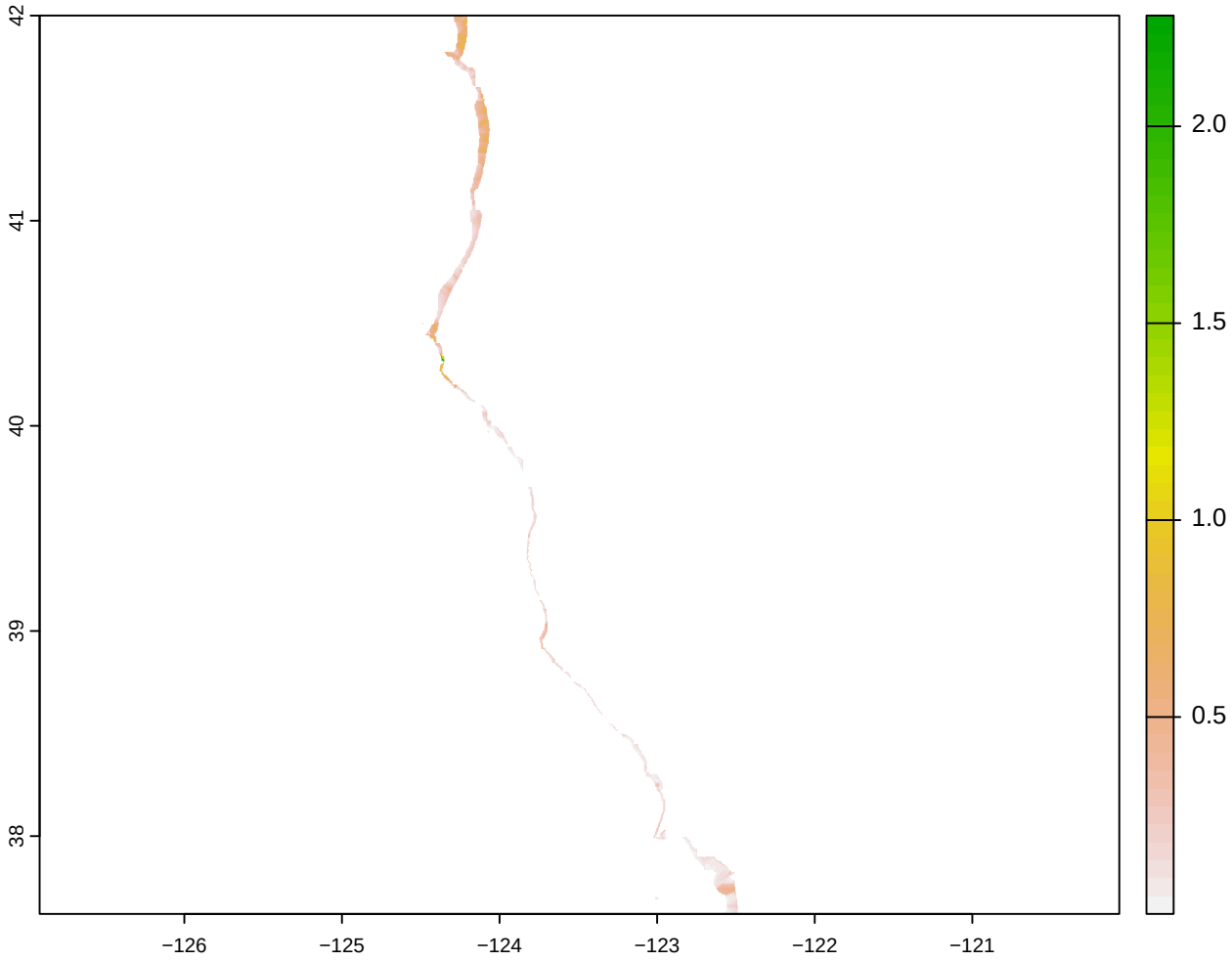
```
## Rows: 22,345
## Columns: 9
## $ x                  <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                  <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD   <dbl> 8.403491, 8.206252, 8.038144, 7.894587, 7.708367, ~
## $ Max_Monthly_Nitrate <dbl> 15.87145, 15.88249, 15.89353, 15.90457, 15.91561, ~
## $ wh_max             <dbl> 7.346423, 7.346423, 7.346423, 7.346423, 7.346423, ~
## $ log_UBR_Max        <dbl> 4.613977, 4.608628, 4.612875, 4.629970, 4.648142, ~
## $ year               <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone               <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name          <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 0.08172101, 0.08548828, 0.08995252, 0.09570659, 0.10299860, 0.1109~
```



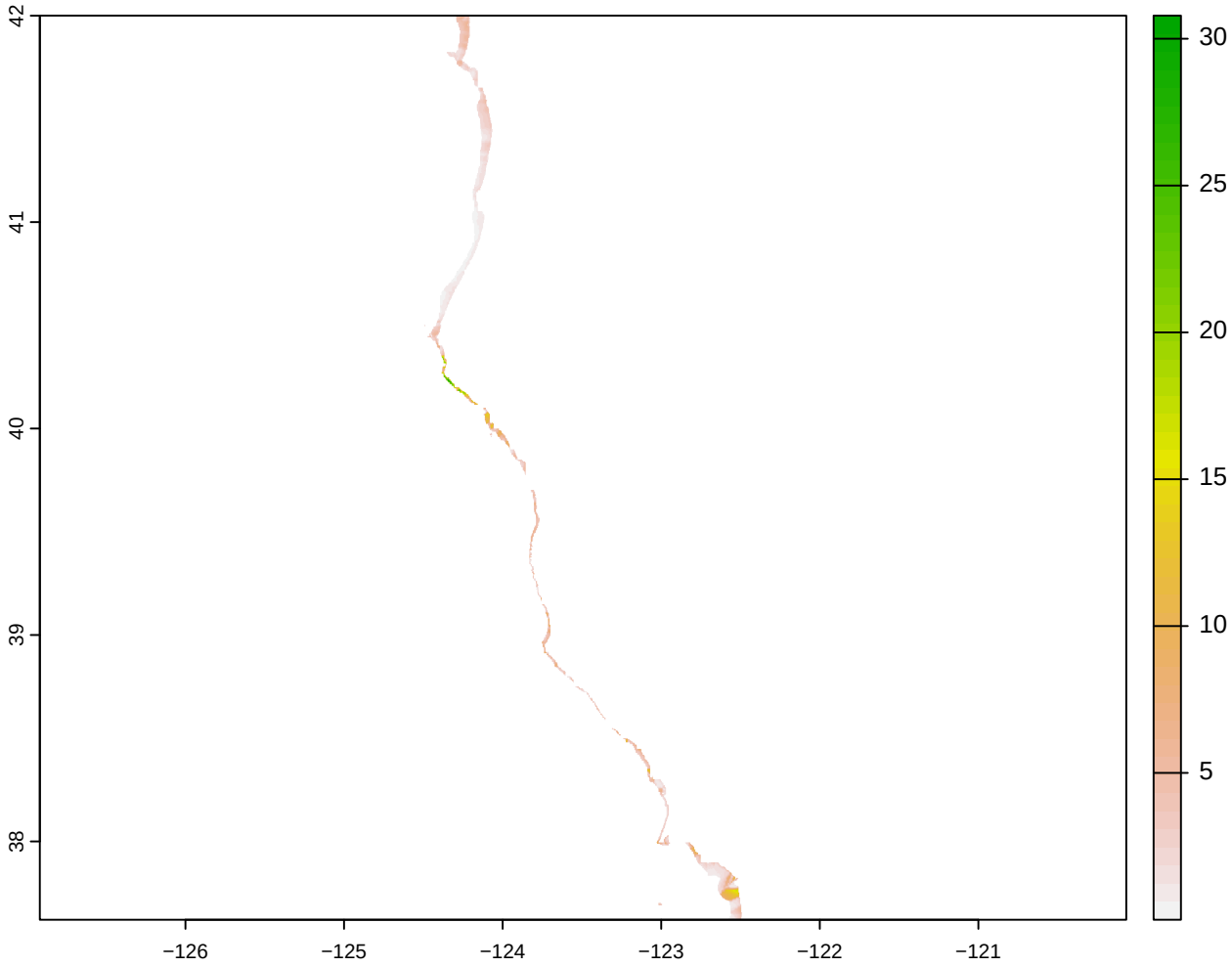

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 5.253853, 5.124660, 5.013935, 4.918759, 4.797251, ~
## $ Max_Monthly_Nitrate <dbl> 11.58300, 11.58587, 11.58874, 11.59161, 11.59449, ~
## $ wh_max              <dbl> 6.833786, 6.833786, 6.833786, 6.833786, 6.833786, ~
## $ log_UBR_Max         <dbl> 4.453473, 4.444874, 4.456473, 4.471694, 4.494325, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 0.04718543, 0.04861080, 0.05120060, 0.05389233, 0.05771196, 0.0613~
```



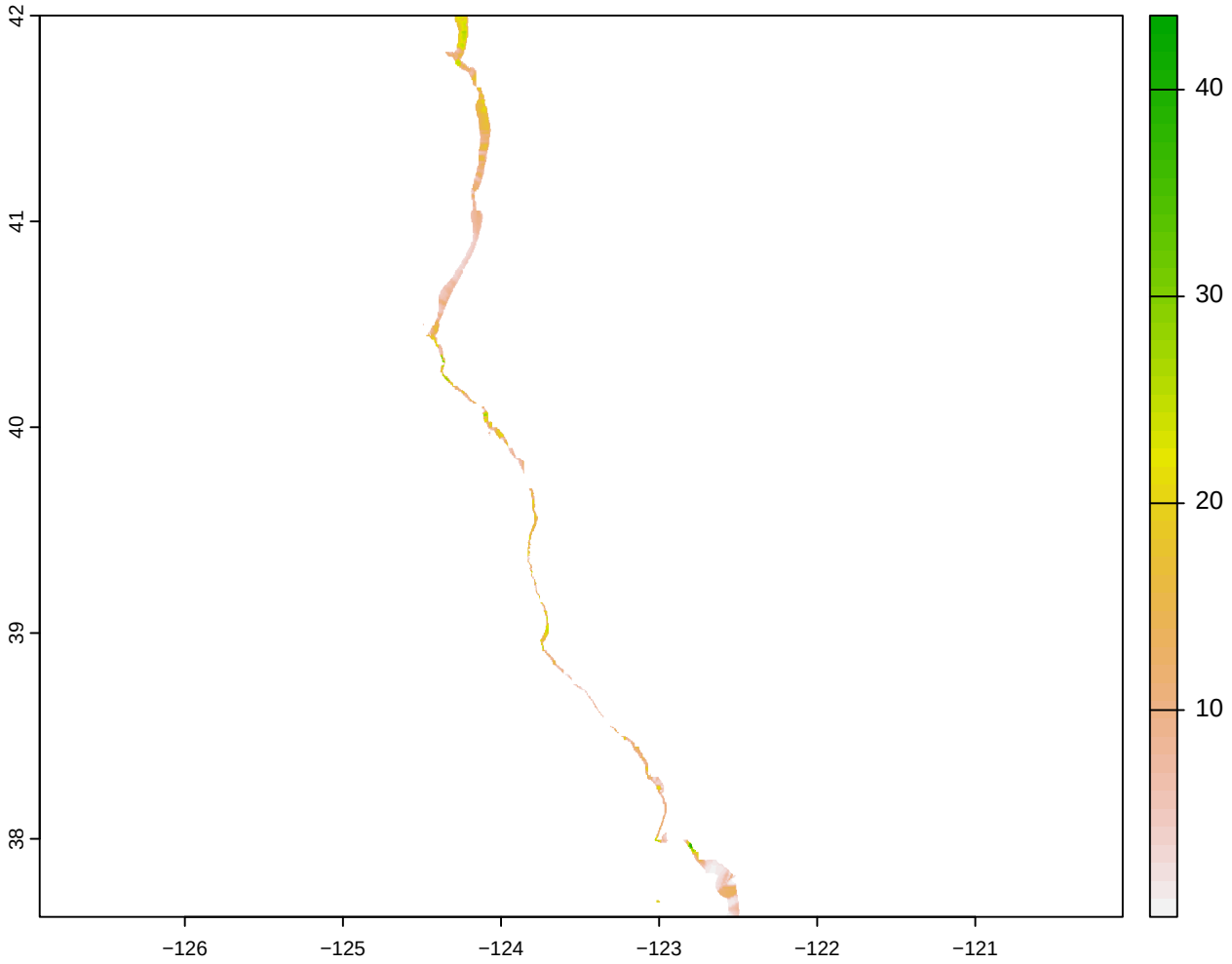

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 0.3152588, 0.3073569, 0.3005700, 0.2947215, 0.2873~
## $ Max_Monthly_Nitrate <dbl> 16.89320, 16.88459, 16.87598, 16.86737, 16.85876, ~
## $ wh_max              <dbl> 7.301894, 7.301894, 7.301894, 7.301894, 7.301894, ~
## $ log_UBR_Max         <dbl> 4.524128, 4.516543, 4.526949, 4.541484, 4.564124, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 0.4198777, 0.4135008, 0.4175831, 0.4241113, 0.4354364, 0.4471158, ~
```



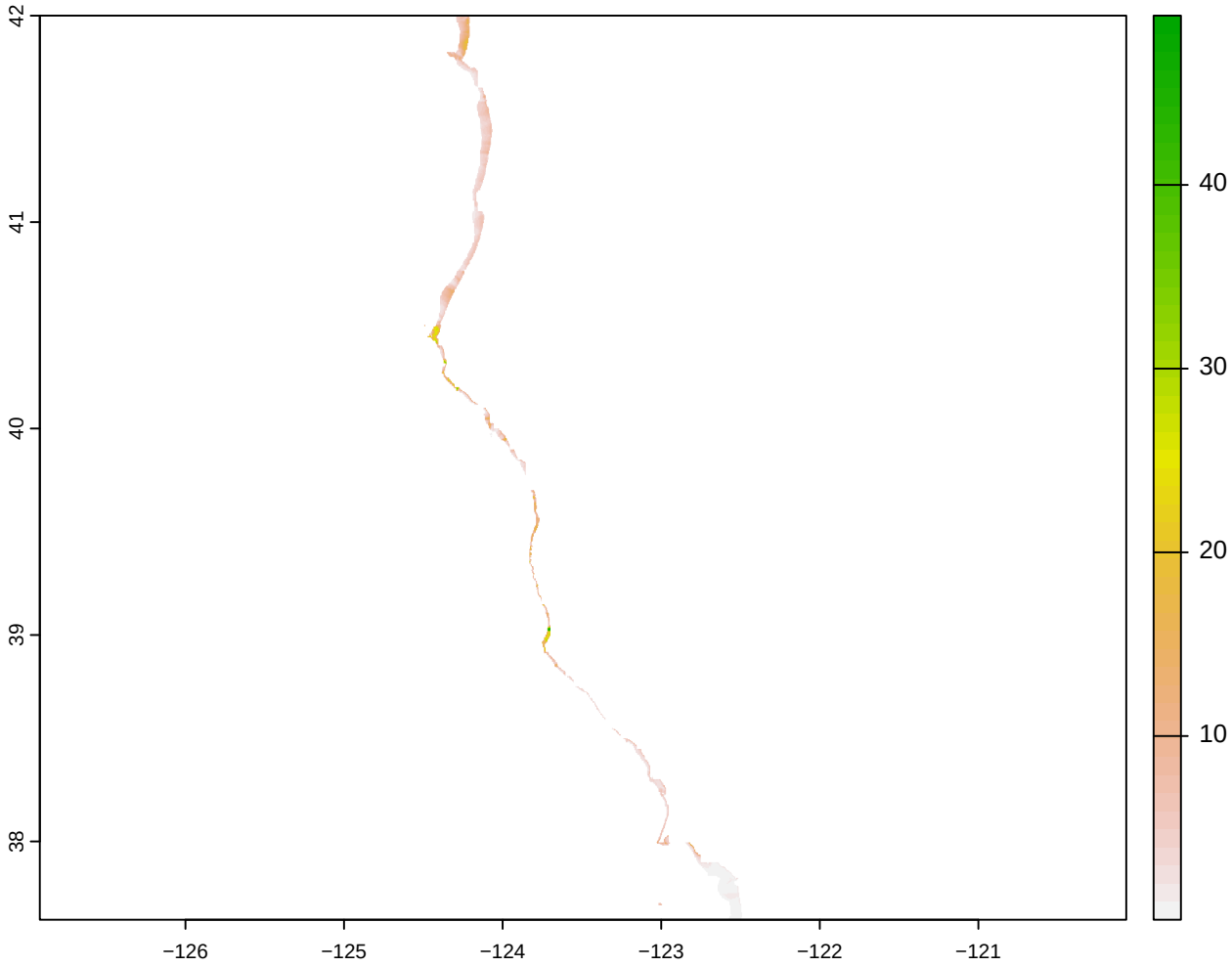

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 2.2842391, 2.2313645, 2.1863749, 2.1480329, 2.0980~
## $ Max_Monthly_Nitrate <dbl> 21.40559, 21.40736, 21.40913, 21.41091, 21.41268, ~
## $ wh_max              <dbl> 7.625381, 7.625381, 7.625381, 7.625381, 7.625381, ~
## $ log_UBR_Max         <dbl> 4.681403, 4.671804, 4.679895, 4.693056, 4.713252, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 3.946527, 3.904195, 3.949351, 4.019672, 4.126512, 4.243005, 4.3426~
```



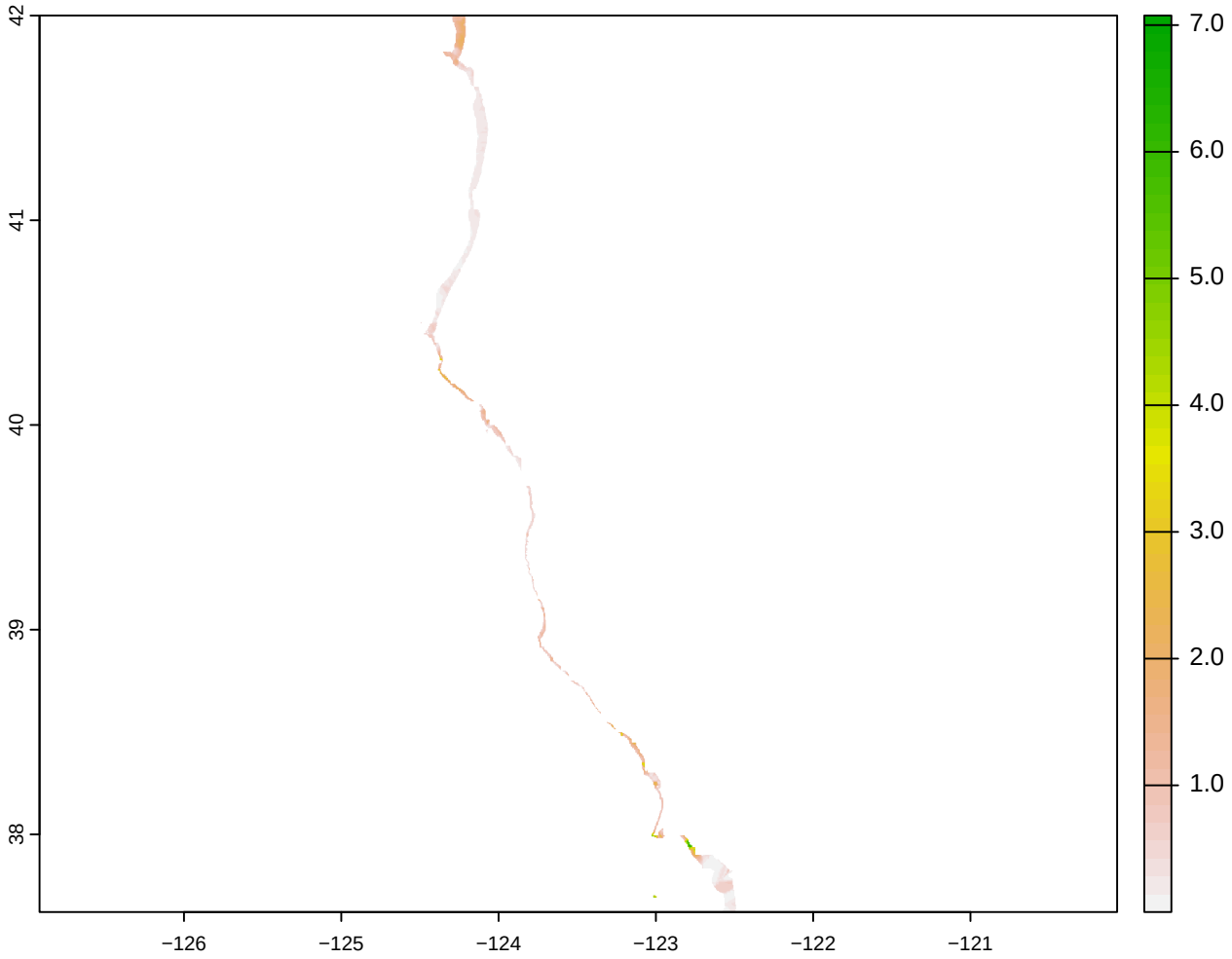

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 2.9830391, 2.9136183, 2.8545103, 2.8040955, 2.7385~
## $ Max_Monthly_Nitrate <dbl> 23.50610, 23.50821, 23.51032, 23.51243, 23.51454, ~
## $ wh_max              <dbl> 9.624915, 9.624915, 9.624915, 9.624915, 9.624915, ~
## $ log_UBR_Max         <dbl> 4.904479, 4.897378, 4.903987, 4.919359, 4.938451, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 17.33206, 17.30398, 17.50585, 17.85453, 18.28393, 18.71787, 19.158~
```



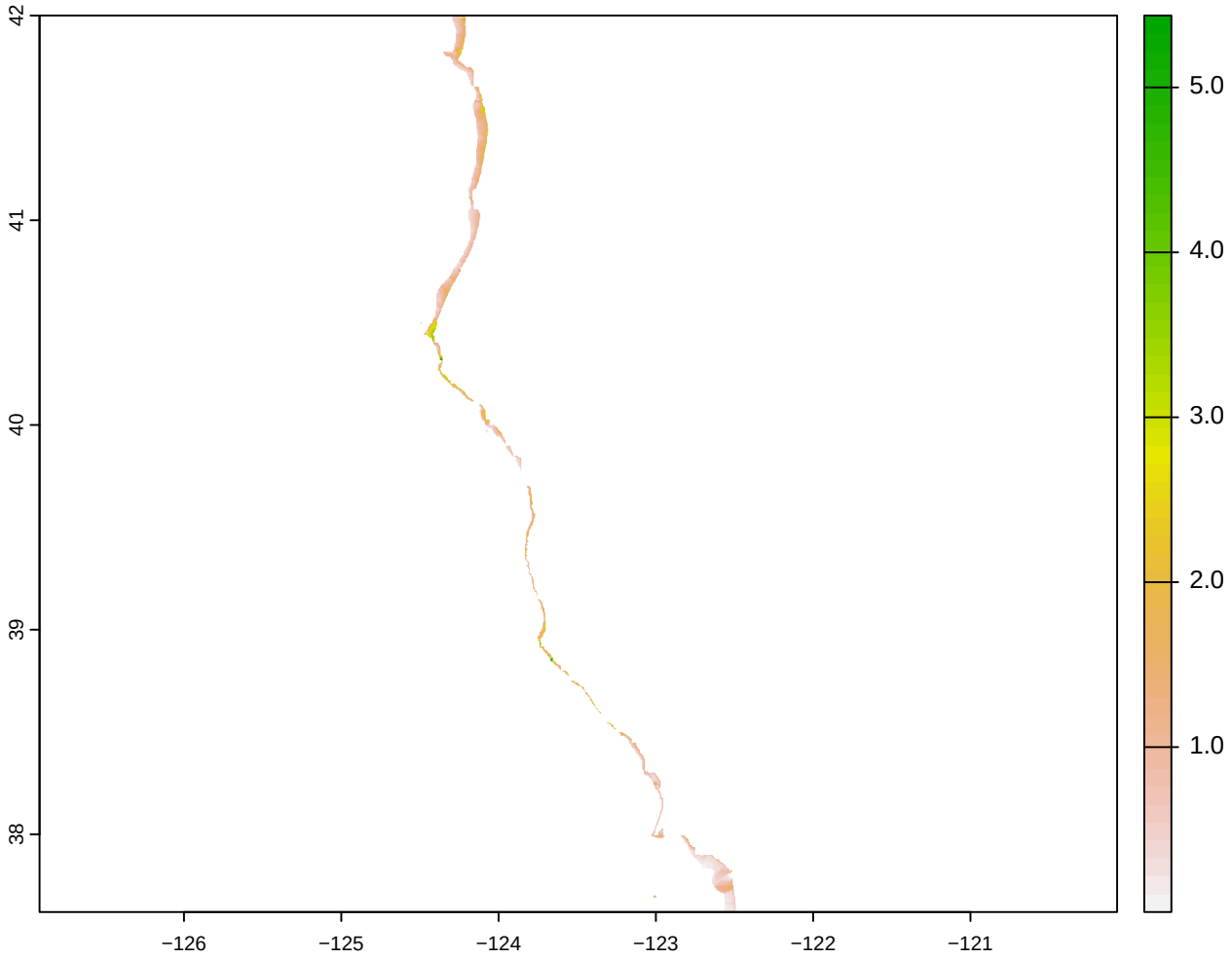

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 2.5072408, 2.4458773, 2.3933079, 2.3481438, 2.2903~
## $ Max_Monthly_Nitrate <dbl> 25.02958, 25.03875, 25.04792, 25.05709, 25.06627, ~
## $ wh_max              <dbl> 6.147168, 6.147168, 6.147168, 6.147168, 6.147168, ~
## $ log_UBR_Max         <dbl> 4.264675, 4.256842, 4.264184, 4.286362, 4.309913, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 3.963362, 3.937319, 4.000107, 4.154094, 4.322648, 4.506188, 4.6739~
```



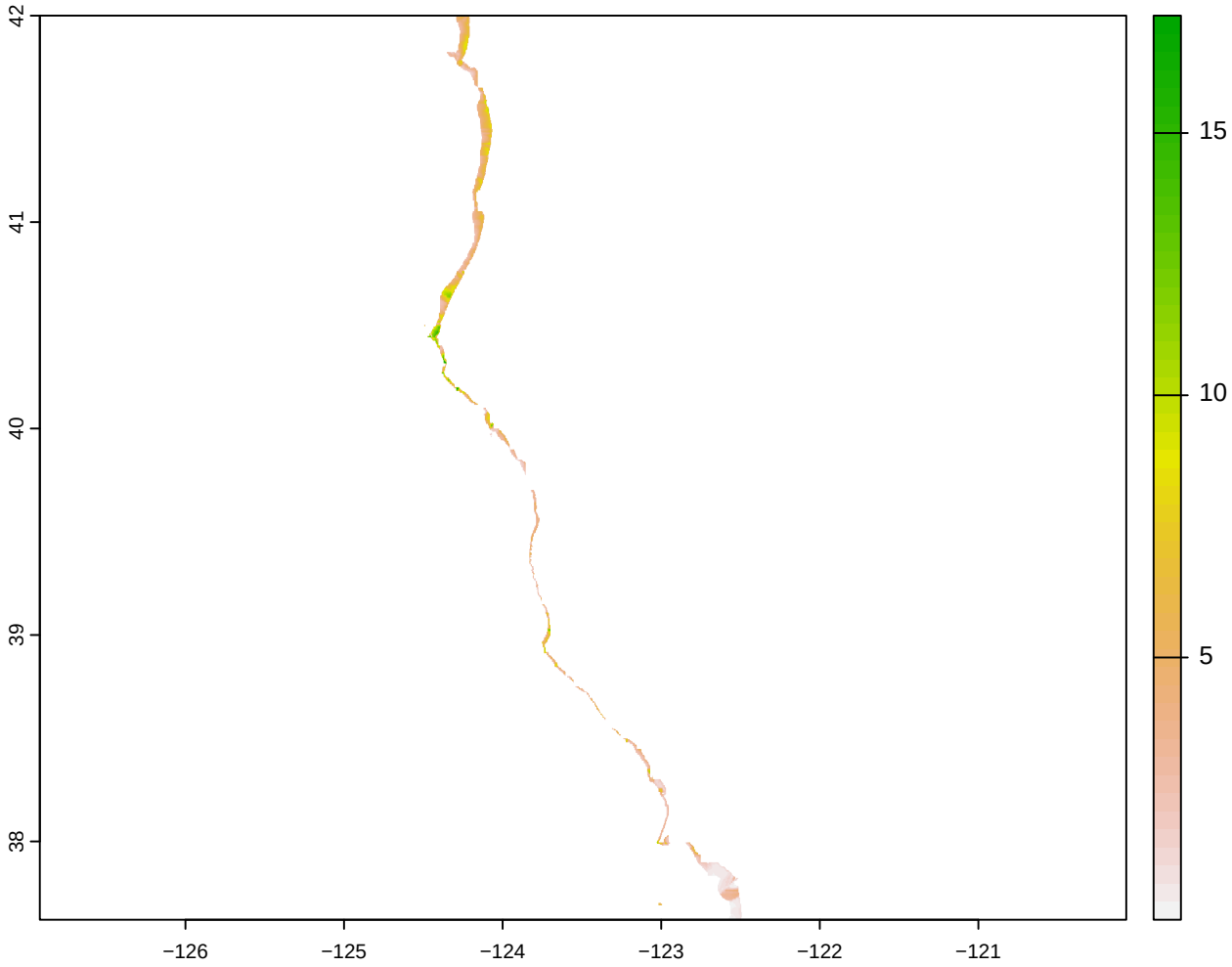

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 2.1213915, 2.0706885, 2.0273731, 1.9902812, 1.9424~
## $ Max_Monthly_Nitrate <dbl> 18.36050, 18.35392, 18.34733, 18.34074, 18.33415, ~
## $ wh_max              <dbl> 7.241228, 7.241228, 7.241228, 7.241228, 7.241228, ~
## $ log_UBR_Max         <dbl> 4.524128, 4.516543, 4.526949, 4.541484, 4.564124, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 0.8914834, 0.8796759, 0.8898943, 0.9052128, 0.9308012, 0.9570823, ~
```



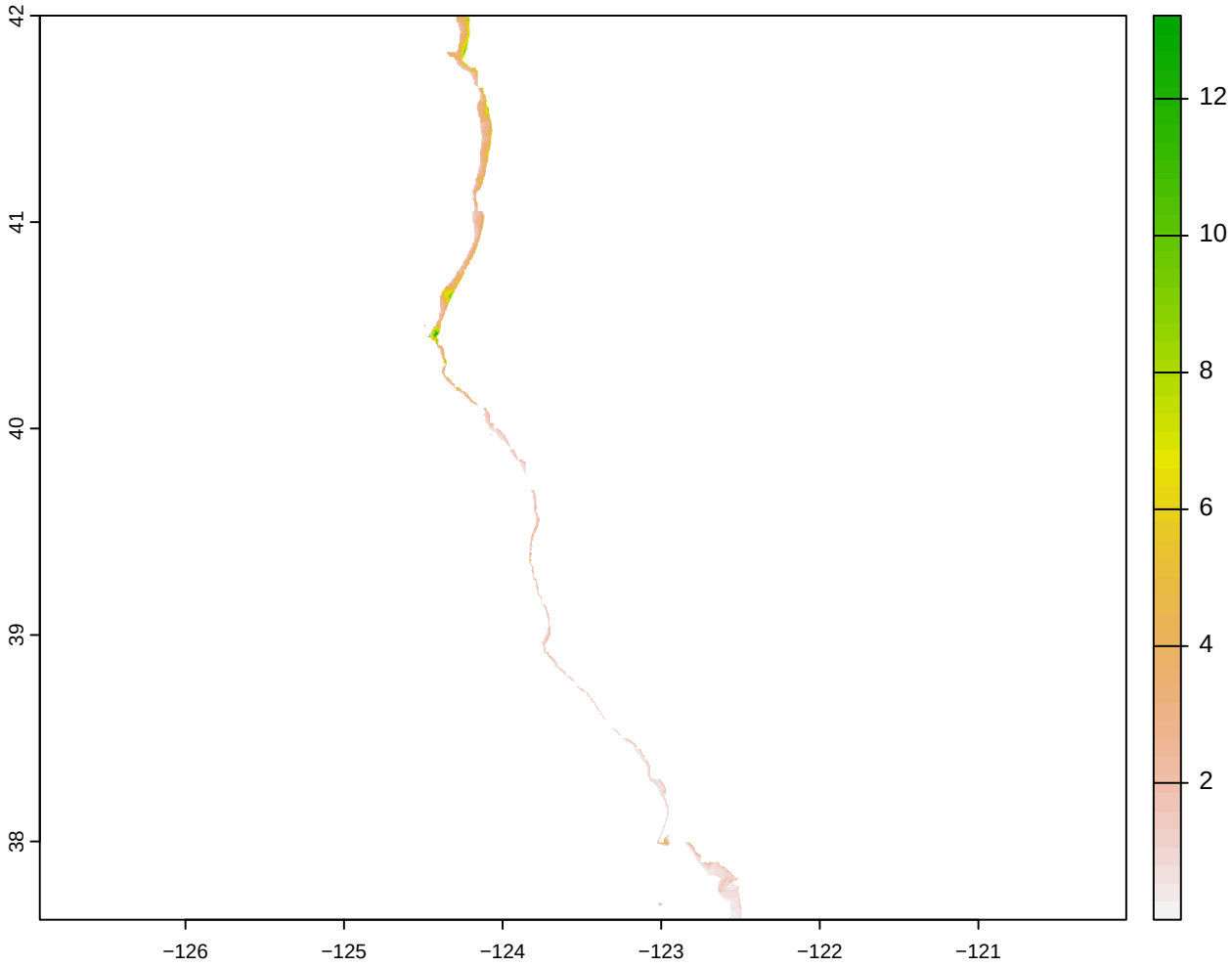

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 2.7642529, 2.6978874, 2.6411619, 2.5925572, 2.5299~
## $ Max_Monthly_Nitrate <dbl> 20.21709, 20.21718, 20.21727, 20.21736, 20.21745, ~
## $ wh_max              <dbl> 5.278422, 5.278422, 5.278422, 5.278422, 5.278422, ~
## $ log_UBR_Max         <dbl> 4.211331, 4.204242, 4.212289, 4.235357, 4.258158, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 0.4705579, 0.4671750, 0.4742490, 0.4922373, 0.5108087, 0.5262909, ~
```



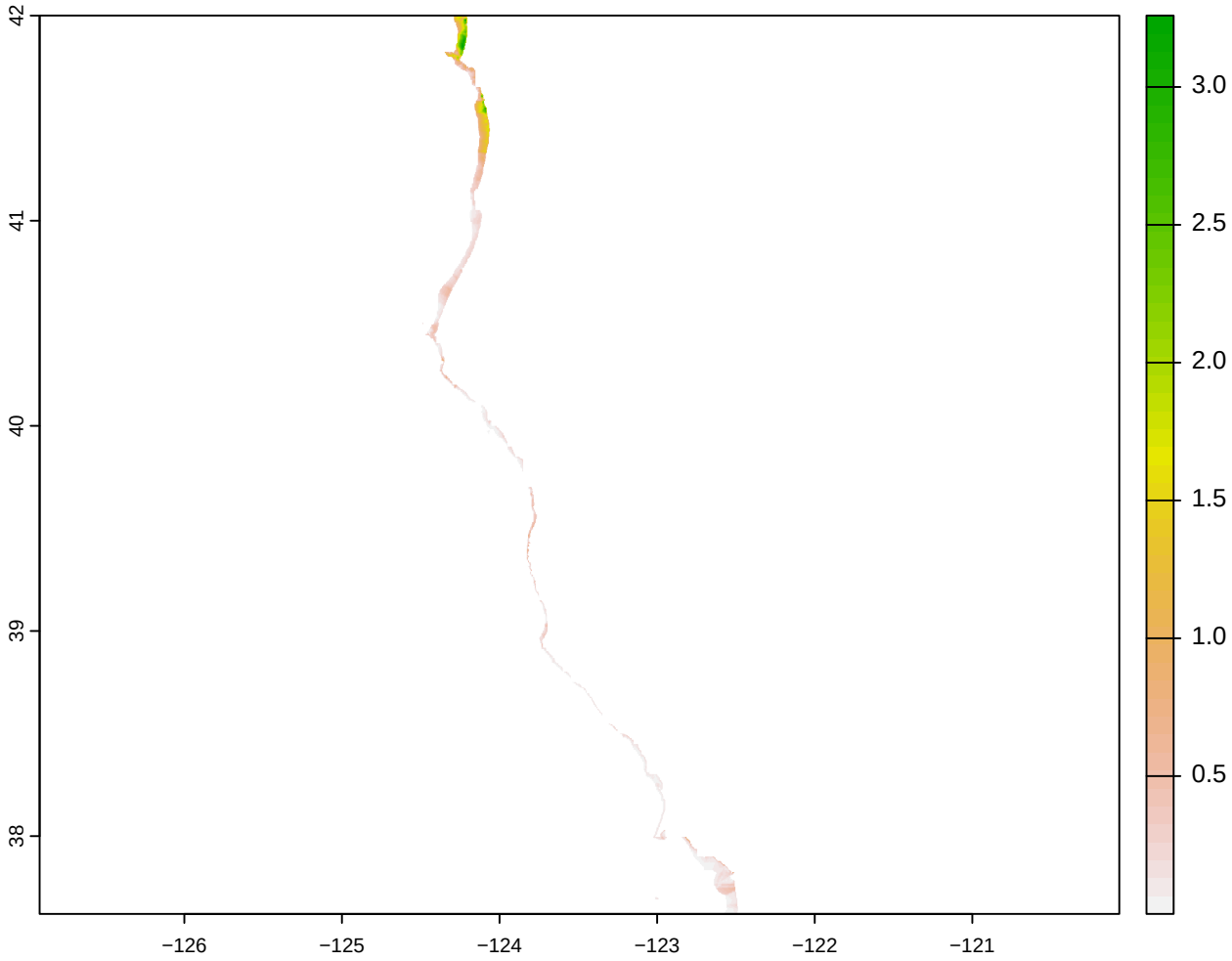

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 2.6352894, 2.5722713, 2.5184336, 2.4723296, 2.4129~
## $ Max_Monthly_Nitrate <dbl> 23.12560, 23.12980, 23.13400, 23.13820, 23.14239, ~
## $ wh_max              <dbl> 6.554802, 6.554802, 6.554802, 6.554802, 6.554802, ~
## $ log_UBR_Max         <dbl> 4.582492, 4.572741, 4.576540, 4.594086, 4.612684, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 3.900274, 3.865157, 3.898799, 4.004302, 4.118341, 4.239741, 4.3501~
```



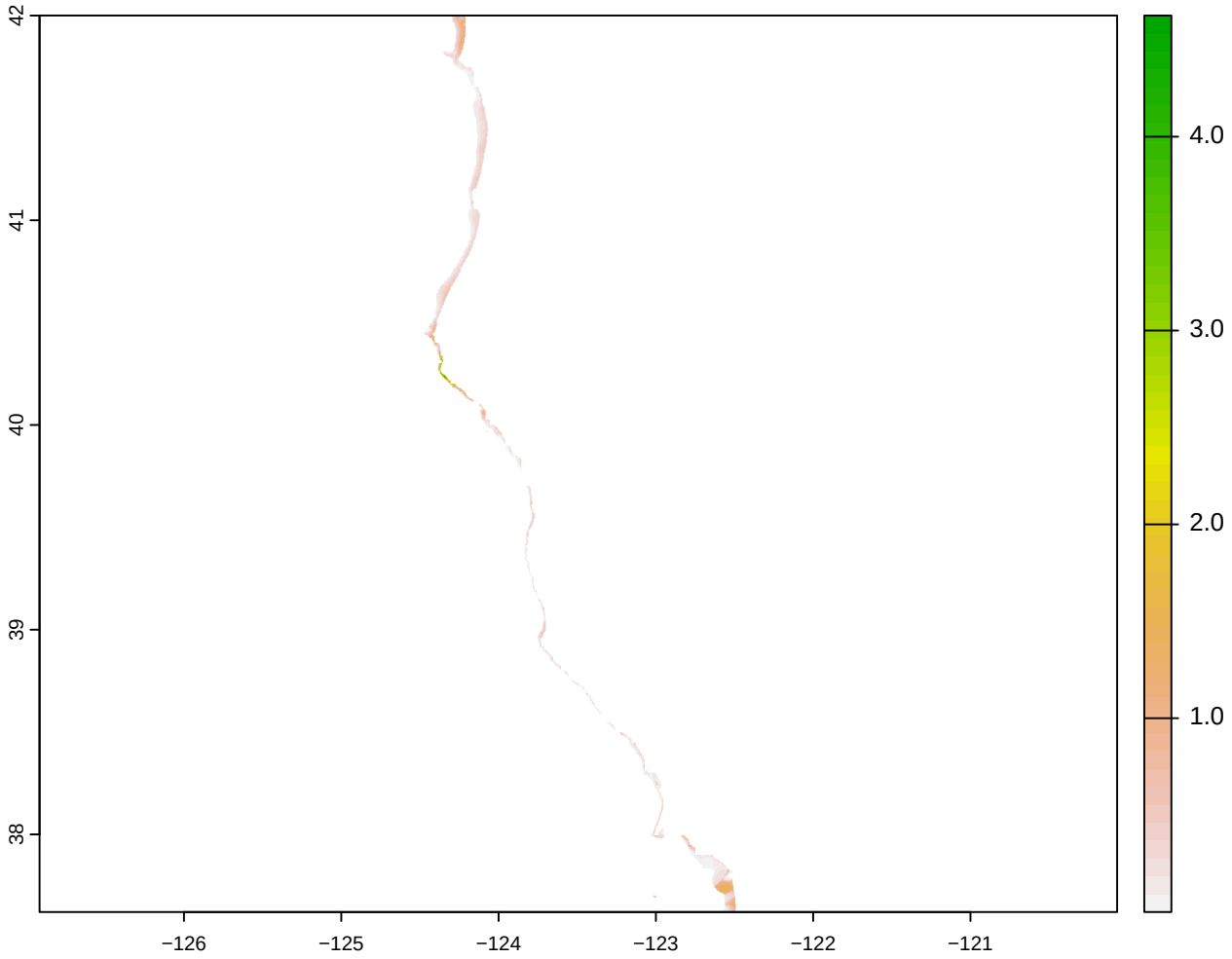

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 1.9696332, 1.9233775, 1.8839484, 1.8502718, 1.8065~
## $ Max_Monthly_Nitrate <dbl> 24.63607, 24.63959, 24.64311, 24.64663, 24.65015, ~
## $ wh_max              <dbl> 5.560881, 5.560881, 5.560881, 5.560881, 5.560881, ~
## $ log_UBR_Max         <dbl> 4.388993, 4.387671, 4.393188, 4.406829, 4.424986, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 3.139994, 3.137245, 3.165816, 3.232567, 3.321495, 3.434900, 3.5251~
```



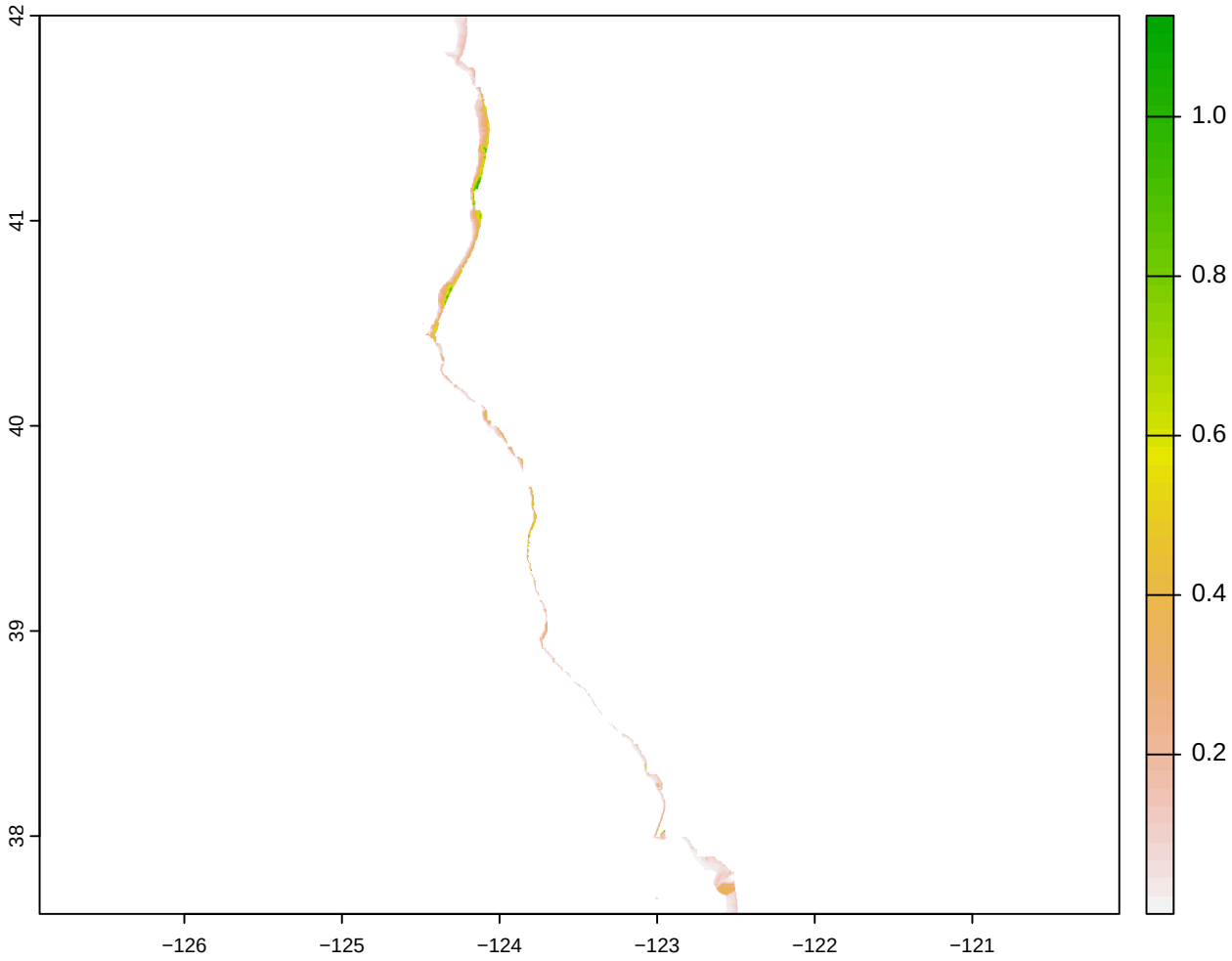

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 4.090216, 3.988507, 3.901207, 3.826037, 3.730417, ~
## $ Max_Monthly_Nitrate <dbl> 18.98832, 18.98432, 18.98033, 18.97633, 18.97234, ~
## $ wh_max              <dbl> 7.151553, 7.151553, 7.151553, 7.151553, 7.151553, ~
## $ log_UBR_Max         <dbl> 4.613977, 4.608628, 4.612875, 4.629970, 4.648142, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 1.067677, 1.079211, 1.100684, 1.138415, 1.181773, 1.228547, 1.2725~
```



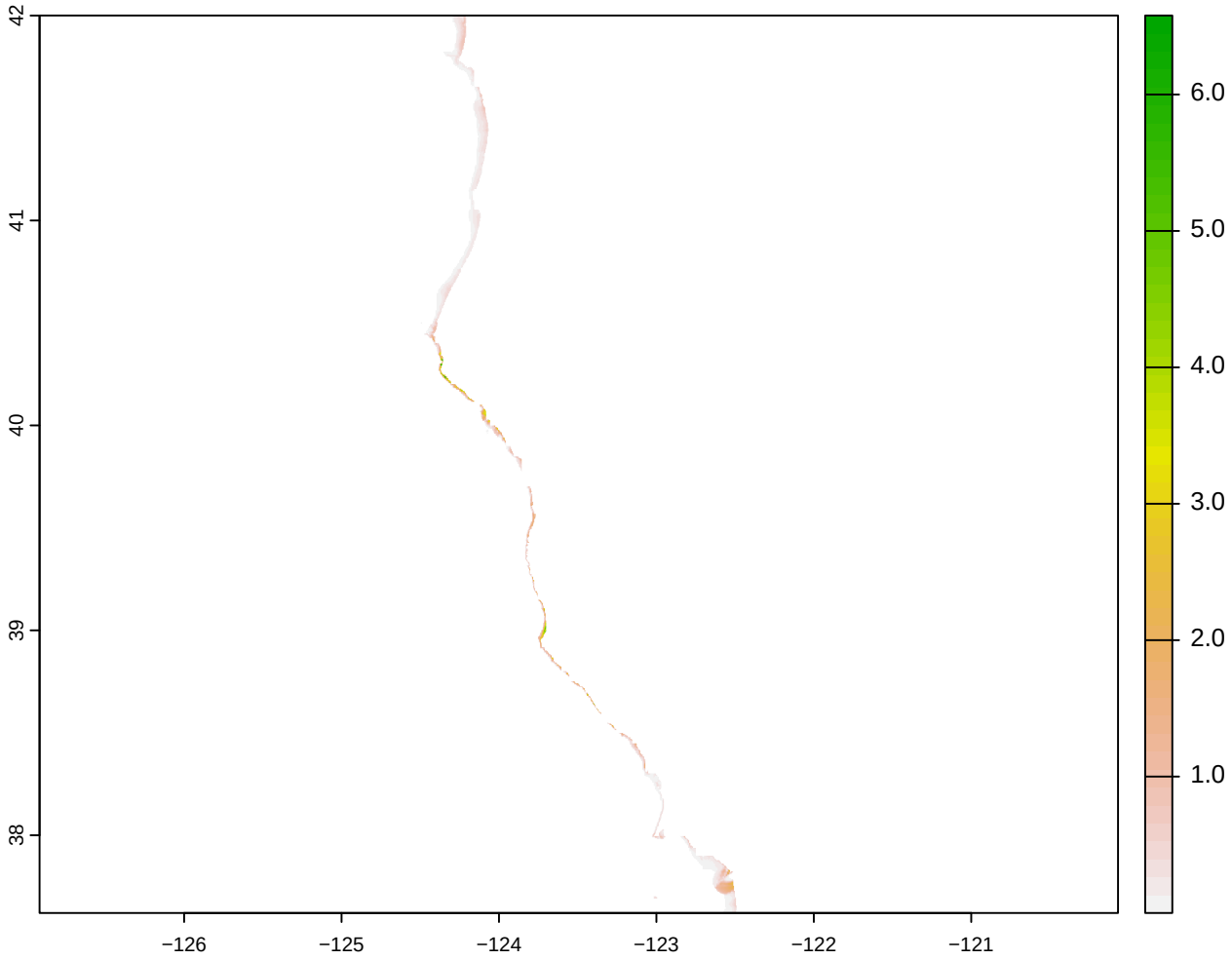

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 6.890228, 6.722425, 6.578753, 6.455404, 6.297413, ~
## $ Max_Monthly_Nitrate <dbl> 16.91011, 16.90354, 16.89698, 16.89042, 16.88386, ~
## $ wh_max              <dbl> 8.630524, 8.630524, 8.630524, 8.630524, 8.630524, ~
## $ log_UBR_Max         <dbl> 4.757161, 4.752329, 4.760861, 4.777849, 4.799056, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 0.3541698, 0.3658536, 0.3821522, 0.4014960, 0.4283802, 0.4565479, ~
```



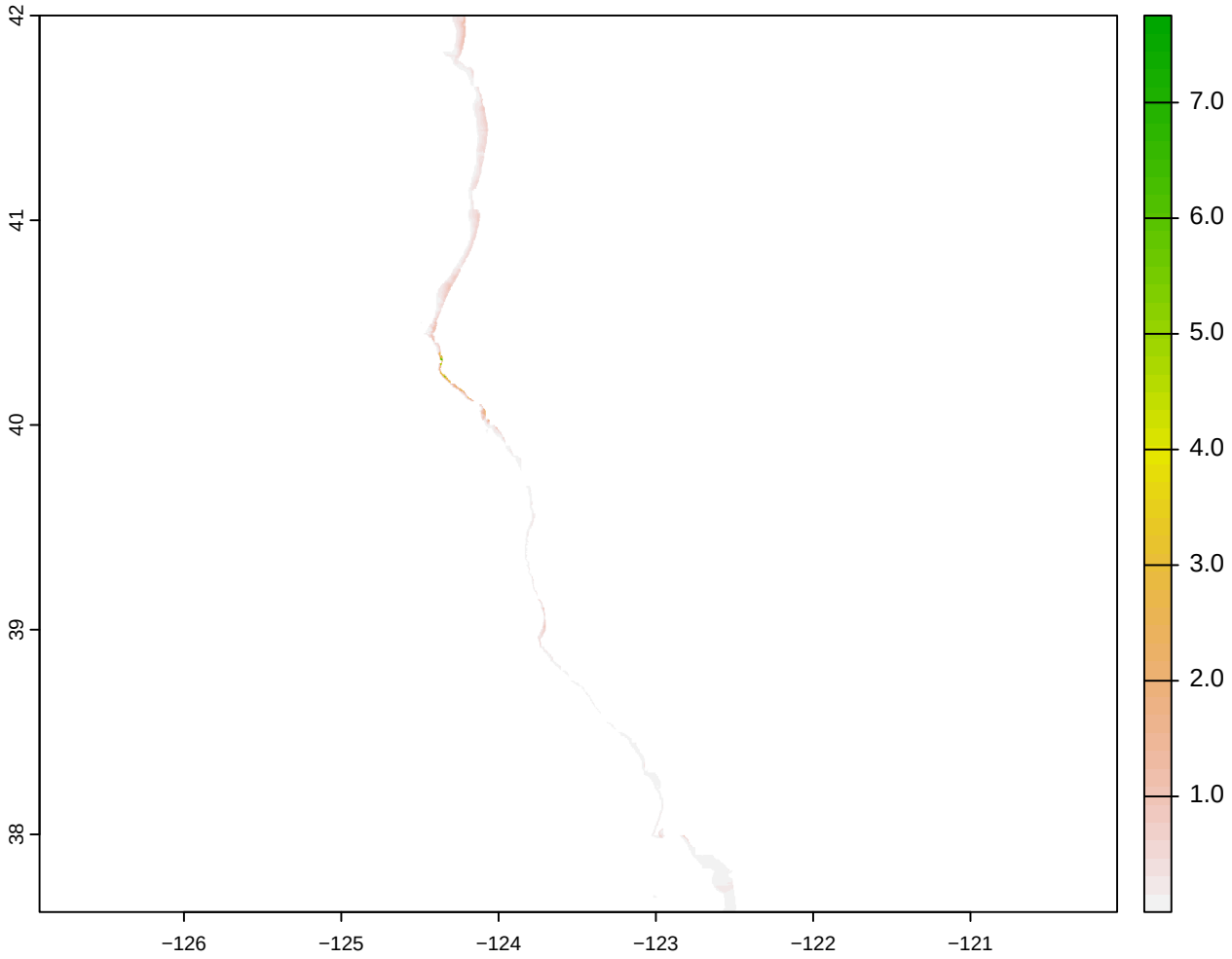

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 7.135033, 6.961007, 6.811979, 6.684005, 6.520174, ~
## $ Max_Monthly_Nitrate <dbl> 12.09677, 12.08993, 12.08310, 12.07626, 12.06943, ~
## $ wh_max              <dbl> 5.770716, 5.770716, 5.770716, 5.770716, 5.770716, ~
## $ log_UBR_Max         <dbl> 4.388993, 4.387671, 4.393188, 4.406829, 4.424986, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 0.01467457, 0.01527381, 0.01596866, 0.01681804, 0.01801038, 0.0194~
```



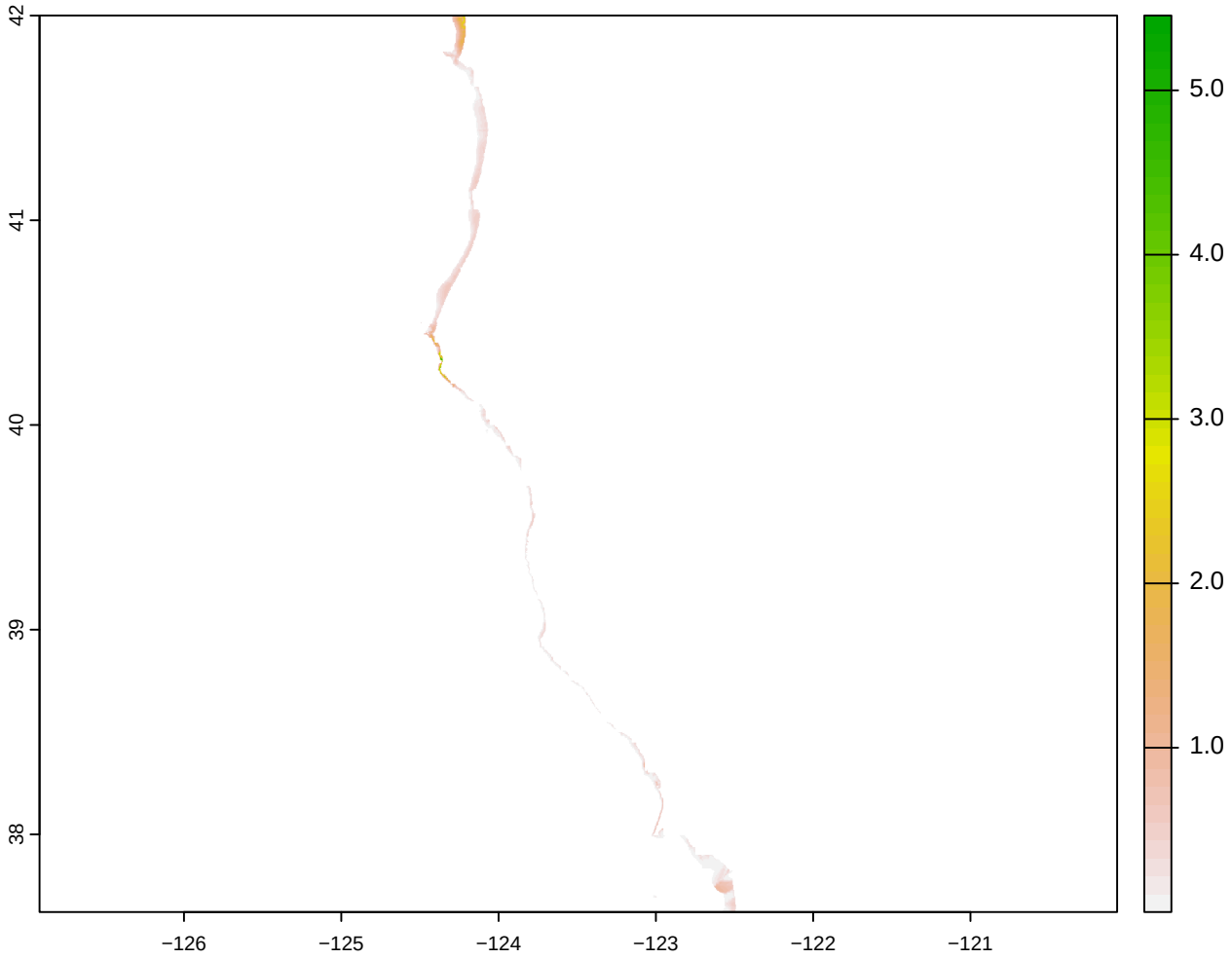

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 9.657516, 9.431939, 9.239817, 9.075893, 8.862899, ~
## $ Max_Monthly_Nitrate <dbl> 17.33237, 17.33315, 17.33393, 17.33470, 17.33548, ~
## $ wh_max              <dbl> 6.878233, 6.878233, 6.878233, 6.878233, 6.878233, ~
## $ log_UBR_Max         <dbl> 4.582492, 4.572741, 4.576540, 4.594086, 4.612684, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 0.0966986, 0.1007453, 0.1060562, 0.1129704, 0.1218945, 0.1313632, ~
```



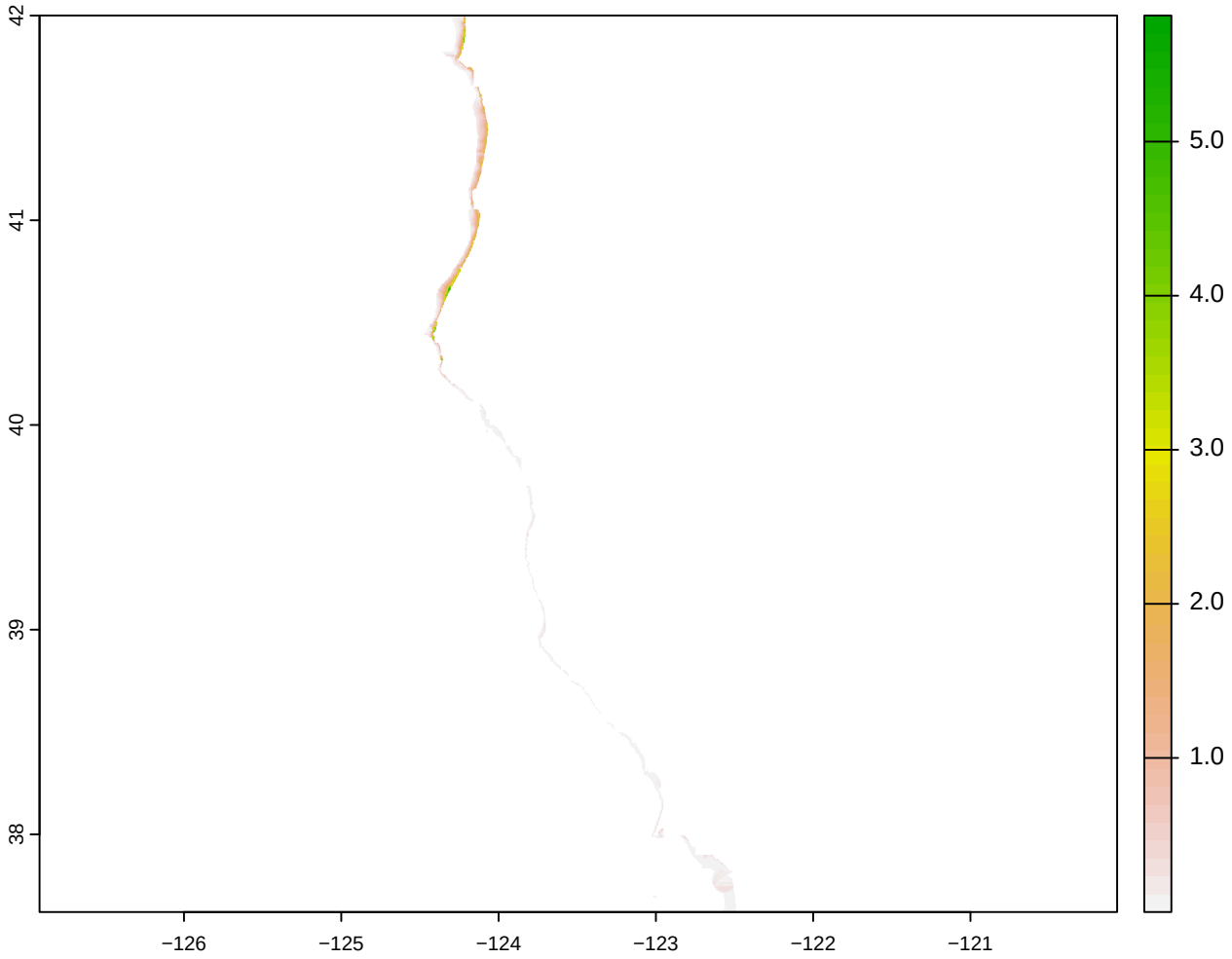

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 10.376705, 10.144278, 9.947333, 9.780320, 9.559979~
## $ Max_Monthly_Nitrate <dbl> 17.45898, 17.44753, 17.43608, 17.42463, 17.41318, ~
## $ wh_max              <dbl> 7.654572, 7.654572, 7.654572, 7.654572, 7.654572, ~
## $ log_UBR_Max         <dbl> 4.681403, 4.671804, 4.679895, 4.693056, 4.713252, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 0.1352912, 0.1404702, 0.1479184, 0.1556377, 0.1672908, 0.1796654, ~
```



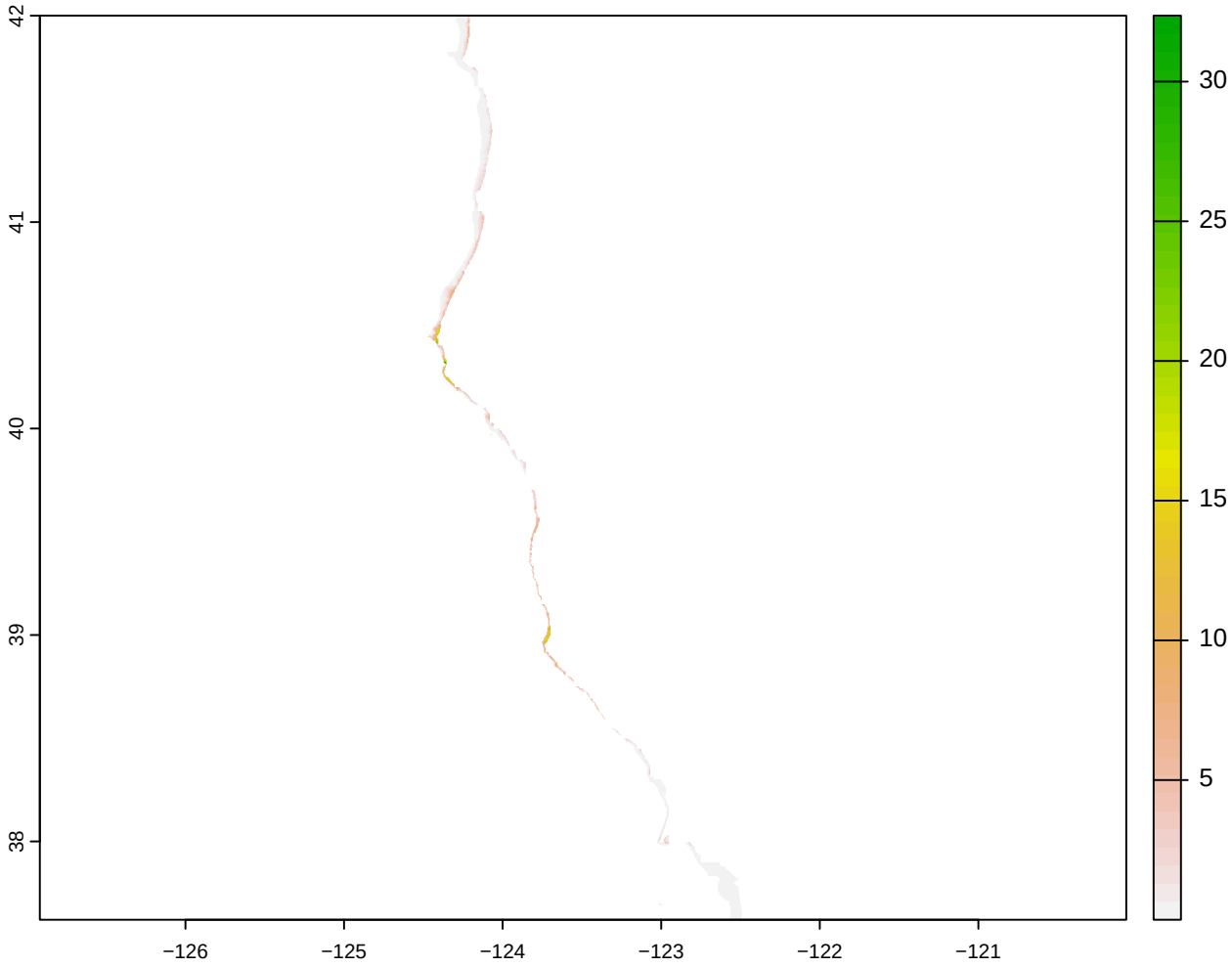

```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 7.802256, 7.635580, 7.495353, 7.377470, 7.219126, ~
## $ Max_Monthly_Nitrate <dbl> 18.82507, 18.80840, 18.79172, 18.77505, 18.75837, ~
## $ wh_max              <dbl> 8.463658, 8.463658, 8.463658, 8.463658, 8.463658, ~
## $ log_UBR_Max         <dbl> 4.699997, 4.694907, 4.698332, 4.715117, 4.737382, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 0.6311820, 0.6480077, 0.6682065, 0.6968658, 0.7386075, 0.7803921, ~
```




```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 22.188297, 21.603207, 21.097811, 20.659426, 20.112~
## $ Max_Monthly_Nitrate <dbl> 21.35229, 21.35367, 21.35505, 21.35643, 21.35781, ~
## $ wh_max              <dbl> 6.300334, 6.300334, 6.300334, 6.300334, 6.300334, ~
## $ log_UBR_Max         <dbl> 4.472725, 4.464328, 4.469220, 4.488180, 4.507039, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 0.01591296, 0.01808743, 0.02055742, 0.02345690, 0.02746035, 0.0318~
```




```
## Rows: 22,345
## Columns: 9
## $ x                   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2~
## $ y                   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, ~
## $ log_den_STRPURAD    <dbl> 35.58071, 34.66059, 33.86744, 33.18111, 32.31900, ~
## $ Max_Monthly_Nitrate <dbl> 24.36407, 24.35111, 24.33816, 24.32520, 24.31225, ~
## $ wh_max              <dbl> 8.412910, 8.412910, 8.412910, 8.412910, 8.412910, ~
## $ log_UBR_Max         <dbl> 4.774401, 4.767812, 4.775306, 4.787709, 4.806518, ~
## $ year                <fct> 2004, 2004, 2004, 2004, 2004, 2004, 2004, 2004, 20~
## $ zone                <fct> OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, OUTER, O~
## $ site_name           <fct> 41.9988440215789, 41.9988440215789, 41.99884402157~
## Rows: 22,345
## Columns: 3
## $ x   <dbl> -124.2896, -124.2868, -124.2840, -124.2812, -124.2784, -124.2756, ~
## $ y   <dbl> 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.99884, 41.998~
## $ fit <dbl> 0.006266850, 0.007709204, 0.009355638, 0.011131258, 0.013911350, 0~
```


42
41
40
39
38
−126
−125
−124
−123
−122
−121
30
25
20
15
10
5