

Prioritizing-potential-aquaculture

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0.1

What Exclusive Economic Zones (eez) on the west Coast of the US are best suited to developing marine aquaculture for several species of oysters and California datemussel.

1 Set-Up

```
# Load in Libraries
library(here)
library(testthat)
library(tidyverse)
library(sf)
library(kableExtra)
library(sp)
library(stars)
library(tmap)
library(terra)
library(viridisLite)
```

```

# Prepare Data

# Bathymetry
depth <- read_stars(here("data/depth.tif"))

# Exclusive Economic Zones (eez)
eez <- st_read(here("data/wc_regions_clean.shp"))

# Sea Surface Temperature (SST) load as a list of .tiff files
sst <- list.files(path= "data",
                    pattern= "average_annual", # file name matching pattern
                    full.names = TRUE) # Reference entire file name matching this pattern

# Stack all rasters files in folder using rast()
sst <- rast(sst)
names(sst) #checking list

```

Check that the datasets have the same coordinate reference system

```

# Check and align CRS for multiple datasets
if (st_crs(depth) == st_crs(eez)) {
  print("Coordinate reference system match!")

} else{
  warning("CRS mismatch between depth and eez")
  # tranfgotm data to match
  depth <- st_transform(depth, st_crs(eez))

}

```

[1] "Coordinate reference system match!"

```

if (st_crs(eez)$wkt != crs(sst)) {
  warning("CRS mismatch between eez and sst")
  sst <- project(sst, st_crs(eez)$wkt)
}

```

Warning: CRS mismatch between eez and sst

2 Process data

- Find the mean SST from 2008-2012 (e.g. create single raster of average SST)
 - convert average SST from Kelvin to Celsius hint: subtract by 273.15
- crop depth raster to match the extent of the SST raster note:
 - the resolutions of the SST and depth data do not match resample the depth data to match the resolution of the SST data using the nearest neighbor approach
 - check that the depth and SST match in resolution, extent, and coordinate reference system

```
# Calculate the SST average
mean_sst <- app(sst[[c("average_annual_sst_2008",
                      "average_annual_sst_2009",
                      "average_annual_sst_2010",
                      "average_annual_sst_2011",
                      "average_annual_sst_2012")]],
                 fun = mean, na.rm = TRUE)
```

```
# Convert average SST from Kelvin to Celsius
sst_mean_celsius <- mean_sst - 273.15
```

```
# First convert depth stars to SpatRaster
depth_rast <- rast(depth)
# crop depth to match SST extent
depth_crop <- crop(depth_rast, sst_mean_celsius)
```

```
# Resample depth_crop to match SST resolution, use method near
depth_resample <- resample(depth_crop,
                           sst_mean_celsius,
                           method = "near")
```

```
#Check resolution match
if (all(dim(depth_resample) == dim(sst_mean_celsius)) &&
    isTRUE(all.equal(res(depth_resample), res(sst_mean_celsius))) &&
    crs(depth_resample) == crs(sst_mean_celsius) &&
    ext(depth_resample) == ext(sst_mean_celsius)) {
  cat(" All raster properties match!\n")
} else {
  cat(" Some properties do not match\n")
}
```

Some properties do not match

```
# Match depth and SST CRS's
crs(depth_resample) <- crs(sst_mean_celsius)

# Stack
ocean_stack <- c(sst_mean_celsius, depth_resample)
names(ocean_stack) <- c("sst", "depth")
cat(" Successfully stacked!\n")
```

Successfully stacked!

3 Find suitable locations for Oysters

To find suitable locations for marine aquaculture, we'll need to find locations that are suitable in terms of both SST and depth. **Oyster** research has show that oysters need the following conditions for optimal growth: - Sea surface Reclassify SST and depth data into locations that are suitable for oysters hint: set suitable values to 1 and unsuitable values to 0 find locations that satisfy both SST and depth conditions

```

# Reclassify SST (11-30°C suitable for oysters)
sst_suitable <- app(sst_mean_celsius, fun = function(x){
  ifelse(x >= 11 & x <= 30, 1, 0) # if temperate is between 11- 30 °C, return 1, else 0
})

# Reclassify Suitable depth range (0-70 meters for oysters)
depth_suitable <- app(depth_resample, fun = function(x){
  ifelse(x >= -70 & x <= 0, 1, 0) # select depths from 0 to 70 meters below surface.
})

# Suitable locations for both conditions
#Use lapp() to multiply the two suitability raster

suitable_locations <- lapp(c(sst_suitable, depth_suitable),
                           fun = function(sst, depth) {
                             sst * depth
                           })

#suitable_locations <- sst_suitable * depth_suitable

```

4 Determine the most suitable EEZ

We want to determine the total suitable area within each EEZ in order to rank zones by priority. To do so, we need to find the total area of suitable locations within each EEZ.

Select suitable cells within West Coast EEZ's find area of grid cells find the total suitable area within each EEZ hint: it might be helpful to rasterize the EEZ data

```

# Rasterize the EEZ data (creates zone IDs)
eez_raster <- rasterize(eez, suitable_locations, field = "rgn")

# Mask suitable locations to EEZ boundaries
suitable_eez <- mask(suitable_locations, eez) # keep only raster cells that fall within the EEZ polygon

#Calculate cell area with cellSize()
cell_area_km2 <- cellSize(suitable_locations, unit = "km") # calculate actual area of each raster cell

# Calculate suitable area per cell
suitable_area <- suitable_eez * cell_area_km2

# Sum suitable are by EEZ zonal statistics
eez_suitable_area <- zonal(suitable_area, eez_raster, fun = "sum", na.rm = TRUE)
colnames(eez_suitable_area) <- c("eez_id", "suitable_area_km2")

# join with eez data
eez$suitable_area_km2 <- eez_suitable_area$suitable_area_km2[match(eez$rgn, eez_suitable_area$eez_id),]

# Rank EEZ data
eez_ranked <- eez[order(-eez$suitable_area_km2), ]

summary_table <- data.frame(
  Rank = 1:nrow(eez_ranked),
  EEZ_Name = eez_ranked$rgn_key,
  Suitable_Area_km2 = round(eez_ranked$suitable_area_km2, 2),
  Percent_of_Total = round(100 * eez_ranked$suitable_area_km2 /

```

```

        sum(eez_ranked$suitable_area_km2), 1)
)

eez_table <- kable(summary_table,
  caption = "EEZ Rankings by Suitable Aquaculture Area",
  col.names = c("Rank", "EEZ Region", "Suitable Area (km2)", "% of Total"),
  align = c("c", "l", "r", "r")) %>%
kable_styling(bootstrap_options = c("striped", "hold_position"),
  full_width = FALSE) %>%
row_spec(0, bold = TRUE, background = "#4CAF50", color = "white") %>%
row_spec(1, bold = TRUE, background = "#E8F5E9") # Highlight top rank

eez_table

```

Table 1: EEZ Rankings by Suitable Aquaculture Area

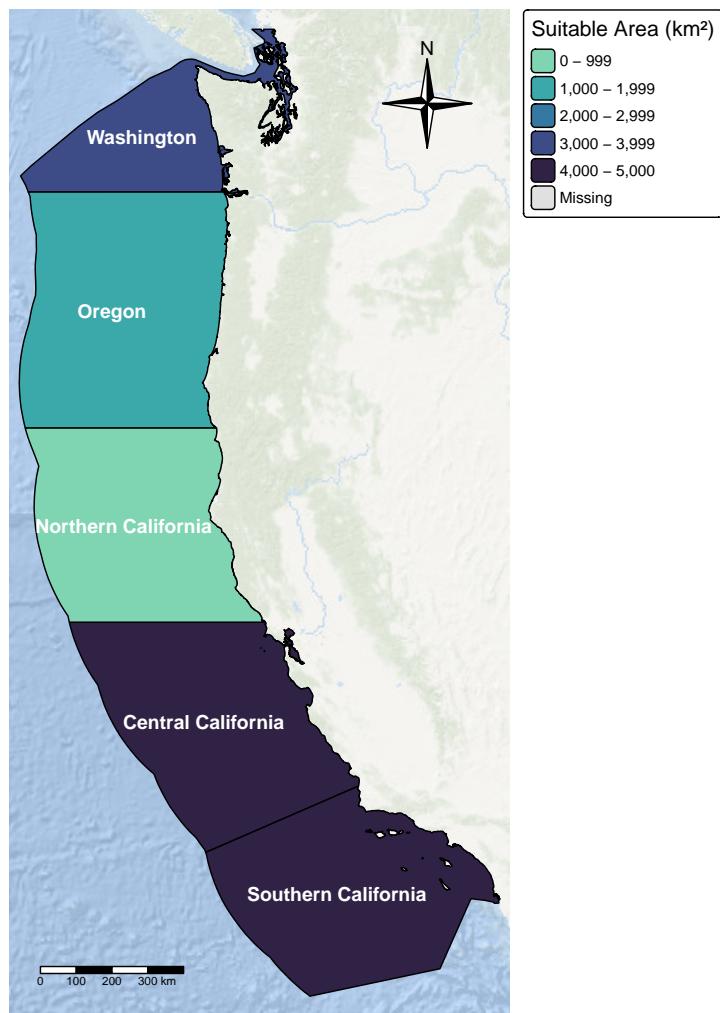
Rank	EEZ Region	Suitable Area (km ²)	% of Total
1	CA-C	4940.04	34.1
2	CA-S	4221.39	29.1
3	WA	3313.16	22.8
4	OR	1578.97	10.9
5	CA-N	454.30	3.1

```

# Map with tmap basic
tm_basemap("Esri.OceanBasemap", alpha = 0.7) +
tm_shape(eez_ranked) +
tm_polygons("suitable_area_km2",
  palette = "-mako",
  title = "Suitable Area (km2)",
  border.col = "black",
  border.lwd = 0.5) +
tm_layout(main.title = "Suitable Oyster Aquaculture Area by EEZ",
  main.title.size = 1.2,
  legend.outsides = TRUE,
  frame = FALSE) +
tm_text("rgn", # Label by region
  size = .8, # Adjust size
  col = "white", # Adjust text color
  fontface = "bold", # Labels are bolded
  xmod = -.5) + # Adjust .5 from the left
tm_compass(type = "4star", position = c("right", "top")) +
tm_scalebar(position = c("left", "bottom"))

```

Suitable Oyster Aquaculture Area by EEZ



5 Workflow for other species using a function

```
find_suitable_aquaculture <- function(sst_raster,
                                       depth_raster,
                                       eez_sf,
                                       sst_min,
                                       sst_max,
                                       depth_min,
                                       depth_max,
                                       species_name) {  
  
  # Reclassify SST
  sst_suitable <- app(sst_raster, fun = function(x) {
    ifelse(x >= sst_min & x <= sst_max, 1, 0)
  })  
  
  # Reclassify depth
  depth_suitable <- app(depth_raster, fun = function(x) {
    ifelse(x >= depth_min & x <= depth_max, 1, 0)
  })  
  
  # Find suitable locations (both conditions)
```

```

suitable_locations <- sst_suitable * depth_suitable
names(suitable_locations) <- species_name

# Mask to EEZ
suitable_in_eez <- mask(suitable_locations, eez_sf)

# Rasterize EEZ
eez_rasterize <- rasterize(eez_sf, suitable_locations, field = "rgn")

# Calculate cell areas
cell_area_km2 <- cellSize(suitable_locations, unit = "km")

# Calculate suitable area per cell (commented out for now)
#suitable_area <- suitable_in_eez * cell_area_km2

# Sum by EEZ zone
eez_suitable_area <- zonal(
  suitable_area,
  eez_rasterize,
  fun = "sum",
  na.rm = TRUE)

colnames(eez_suitable_area) <- c("EEZ_ID", "Suitable_Area_km2")

# Join with EEZ data and rank
eez_sf$suitable_area_km2 <-
  eez_suitable_area$Suitable_Area_km2[
    match(eez_sf$rgn, eez_suitable_area$EEZ_ID)]
eez_ranked <- eez_sf[order(-eez_sf$suitable_area_km2), ]

# Create summary table
summary_table <- data.frame(
  Rank = 1:nrow(eez_ranked),
  EEZ = eez_ranked$rgn_key,
  Suitable_Area_km2 = round(eez_ranked$suitable_area_km2, 2)
)

# Return results as a list
results <- list(
  species = species_name,
  sst_suitable = sst_suitable,
  depth_suitable = depth_suitable,
  suitable_locations = suitable_locations,
  suitable_in_eez = suitable_in_eez,
  eez_ranked = eez_ranked,
  summary_table = summary_table
)

return(results)
}

```

6 Apply function to species of choice

6.1 Adula californiensis (Philippi, 1847)

- Common Name: California datemussel
- Low Fishing Vulnerability
 - Depth range: 0-20 meters
 - Temperature: 9.1-18.6 C
- Source: SeaLifeBase

```
# Mussels (different requirements)
mussel_results <- find_suitable_aquaculture(
  sst_raster = sst_mean_celsius,
  depth_raster = depth_resample,
  eez_sf = eez,
  sst_min = 9.1,
  sst_max = 18.6,
  depth_min = 0,
  depth_max = 20,
  species_name = "California Datemussel"
)

# Access results
kable(mussel_results$summary_table)
```

Rank	EEZ	Suitable_Area_km2
1	WA	260.91
2	CA-S	124.68
3	CA-C	103.50
4	OR	76.65
5	CA-N	33.36

```
# Plot Mussel EEZ
#| fig.width: 15
#| fig.height: 8

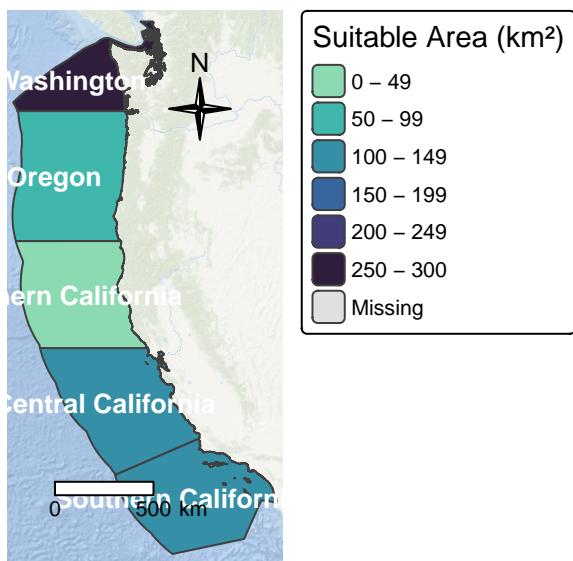
tm_basemap("Esri.OceanBasemap", alpha = 0.7) +
#tm_shape(mussel_results$suitable_in_eez) +
tm_raster() +
tm_shape(mussel_results$eez_ranked) +
tm_polygons("suitable_area_km2",
            palette = "-mako",
            title = "Suitable Area (km2)", boarder.col = "black",
            border.lwd = 0.5) +
tm_layout(main.title ="Suitable Mussel Aquaculture Area by EEZ",
          main.title.size =1.2,legend.outsides =TRUE,frame =FALSE) +
tm_text("rgn", # Label by region
        size = .8, # Adjust size
        col = "white", # Adjust text color
        fontface = "bold", # Labels are bolded
        xmod = -.5) + # Adjust .5 from the left
tm_compass(type = "4star",
           position = c("right", "top")),
```

```

    size = 2) +
tm_scale_bar(position = c("left", "bottom"),
              text.size = 0.7)

```

Suitable Mussel Aquaculture Area by EEZ



7 Reflections

Reflections must be clear, accurate, and demonstrate a deep understanding of the analysis performed

This analysis identified suitable locations for oyster aquaculture along the West Coast EEZs by integrating sea surface temperature (SST) and bathymetric data. The workflow demonstrated how geospatial analysis can support marine resource management decisions by combining environmental constraints with jurisdictional boundaries. In the analysis we found that 2.3% (based on cellsize) of the West Coast EEZ area meets the suitability criteria for oyster cultivation (11-30°C SST, 0-70m depth). CA-C (Central California) ranked highest with 4940.04 km² of suitable area, suggesting it as the priority zone for aquaculture development.

8 Cite

Hall, S. J., Delaporte, A., Phillips, M. J., Beveridge, M. & O'Keefe, M. Blue Frontiers: Managing the Environmental Costs of Aquaculture (The WorldFish Center, Penang, Malaysia, 2011).

Gentry, R. R., Froehlich, H. E., Grimm, D., Kareiva, P., Parke, M., Rust, M., Gaines, S. D., & Halpern, B. S. Mapping the global potential for marine aquaculture. *Nature Ecology & Evolution*, 1, 1317-1324 (2017).

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