Ocean Acidification Monitoring Inventory Gap Analysis

## Step 1. Manipulate sea surface temperature and dissolved oxygen as proxies for ocean acidificiation change

#### Load packages

if (!require(pacman)) install.packages("pacman")  
library(pacman)  
p\_load(  
 tidyverse, here, glue,  
 raster,  
 sdmpredictors, dismo,   
 deldir,   
 mapview,  
 tmap)  
  
devtools::load\_all(here("../oatools"))

#### Set paths and variables

dir\_data <- here("data")  
dir\_sdmdata\_old <- here("data/sdmpredictors")  
dir\_cache <- here("cache")  
dir\_sdmdata <- here("cache/sdmpredictors")  
  
SST\_tif <- here("data/sst\_mean.tif")  
DO\_tif <- here("data/do\_mean.tif")

#### Set cache

if (!dir.exists(dir\_data)) dir.create(dir\_data)  
if (!dir.exists(dir\_cache)) dir.create(dir\_cache)  
if (!dir.exists(dir\_sdmdata) & dir.exists(dir\_sdmdata\_old))  
 file.rename(dir\_sdmdata\_old, dir\_sdmdata)  
if (!dir.exists(dir\_sdmdata)) dir.create(dir\_sdmdata)

#### Set extent and coordinate reference system

ext\_study <- extent(-670000, 350000, -885000, 1400000)  
crs\_study <- '+init=EPSG:6414'

#### Create sea surface temperature layer (mean and range)

r\_sst\_mean\_nofill <- lyr\_to\_tif(  
 lyr = "BO\_sstmean",   
 tif = here("data/sst\_mean.tif"),  
 crs = crs\_study,  
 dir\_sdm\_cache = dir\_sdmdata,  
 extent\_crop = ext\_study,   
 redo=T, fill\_na=FALSE)  
  
r\_sst\_mean <- lyr\_to\_tif(  
 lyr = "BO\_sstmean",   
 tif = here("data/sst\_mean.tif"),  
 crs = crs\_study,  
 dir\_sdm\_cache = dir\_sdmdata,  
 extent\_crop = ext\_study,   
 redo=T, fill\_na=TRUE, fill\_window=11) #caclulate mean  
  
n\_na\_nofill <- sum(is.na(raster::getValues(r\_sst\_mean\_nofill)))  
n\_na <- sum(is.na(raster::getValues(r\_sst\_mean)))  
  
r\_sst\_range\_nofill <- lyr\_to\_tif(  
 lyr = "BO\_sstrange",   
 tif = here("data/sst\_range.tif"),  
 crs = crs\_study,  
 dir\_sdm\_cache = dir\_sdmdata,  
 extent\_crop = ext\_study,   
 redo=T, fill\_na=FALSE)  
  
r\_sst\_range <- lyr\_to\_tif(  
 lyr = "BO\_sstrange",   
 tif = here("data/sst\_range.tif"),  
 crs = crs\_study,  
 dir\_sdm\_cache = dir\_sdmdata,  
 extent\_crop = ext\_study,   
 redo=T, fill\_na=TRUE, fill\_window=11)

#### Create dissolved oxygen layer (mean and range)

r\_do\_mean\_nofill <- lyr\_to\_tif(  
 lyr = "BO\_dissox",   
 tif = here("data/do\_mean.tif"),  
 crs = crs\_study,  
 dir\_sdm\_cache = dir\_sdmdata,  
 extent\_crop = ext\_study,   
 redo=T, fill\_na=FALSE)  
  
r\_do\_mean <- lyr\_to\_tif(  
 lyr = "BO\_dissox",   
 tif = here("data/do\_mean.tif"),  
 crs = crs\_study,  
 dir\_sdm\_cache = dir\_sdmdata,  
 extent\_crop = ext\_study,   
 redo=T, fill\_na=TRUE, fill\_window=11) #calculate mean  
  
r\_do\_range\_nofill <- lyr\_to\_tif(  
 lyr = "BO2\_dissoxrange\_bdmin",   
 tif = here("data/do\_range.tif"),  
 crs = crs\_study,  
 dir\_sdm\_cache = dir\_sdmdata,  
 extent\_crop = ext\_study,   
 redo=T, fill\_na=FALSE)  
  
r\_do\_range <- lyr\_to\_tif(  
 lyr = "BO2\_dissoxrange\_bdmin",   
 tif = here("data/do\_range.tif"),  
 crs = crs\_study,  
 dir\_sdm\_cache = dir\_sdmdata,  
 extent\_crop = ext\_study,   
 redo=T, fill\_na=TRUE, fill\_window=11)

## Step 2. Relate SST and DO trends to each monitoring site

#### Load monitoring inventory

inventory <- read\_csv(here("data/inventory.csv"))

#### Tidy Inventory

1. Isolate OAH Focus Data Collection
2. Quantify Data Collection Frequency (measurements/year)
3. Remove NA coordinate entries from gliders
4. Transform latitude and longitude to numeric
5. Create subsets of data

oahfocus <- subset(inventory, OAHFocus == "OA" | OAHFocus == "H" | OAHFocus == "OAH") #remove non OAH focus entries  
  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Once"] <- 0  
oahfocus$MeasFreq[oahfocus$MeasFreq == 10] <- 52560  
oahfocus$MeasFreq[oahfocus$MeasFreq =="< 6 hours"] <- 1460  
oahfocus$MeasFreq[oahfocus$MeasFreq == 60] <- 8760  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Daily"] <- 365  
oahfocus$MeasFreq[oahfocus$MeasFreq ==30] <- 17520  
oahfocus$MeasFreq[oahfocus$MeasFreq == 20] <- 26280  
oahfocus$MeasFreq[oahfocus$MeasFreq == 15] <- 35040  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Quarterly"] <- 4  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Annual"] <- 1  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Monthly"] <- 12  
oahfocus$MeasFreq[oahfocus$MeasFreq == 5] <- 105120  
oahfocus$MeasFreq[oahfocus$MeasFreq == 6] <- 87600  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Semi-annual"] <- 2  
oahfocus$MeasFreq[oahfocus$MeasFreq == 180] <- 2920  
oahfocus$MeasFreq[oahfocus$MeasFreq == 2] <- 262800  
oahfocus$MeasFreq[oahfocus$MeasFreq == 0.25] <- 2102400  
oahfocus$MeasFreq[oahfocus$MeasFreq == 3] <- 175200  
oahfocus$MeasFreq[oahfocus$MeasFreq == 1] <- 525600  
oahfocus$MeasFreq[oahfocus$MeasFreq == 120] <- 2920  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Bi-weekly"] <- 26  
oahfocus$MeasFreq[oahfocus$MeasFreq == 360] <- 1460  
oahfocus$MeasFreq[oahfocus$MeasFreq == 720] <- 730  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Seasonally"] <- 1  
oahfocus$MeasFreq[oahfocus$MeasFreq =="1/4 second"] <- 126144000  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Bi-monthly"] <- 6  
oahfocus$MeasFreq[oahfocus$MeasFreq =="5 Years"] <- 0.2  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Bi-weekly"] <- 26  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Variable"] <- 0  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Decadal"] <- 0.1  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Biennial"] <- 0.5  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Weekly"] <- 52  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Triennial"] <- 0.33333  
oahfocus$MeasFreq[oahfocus$MeasFreq =="Trimester"] <- 3  
#quantify frequencies  
  
unique(oahfocus$MeasFreq)

## [1] "4" "8760" "1460" "0" "525600"   
## [6] "126144000" "35040" "17520" NA "2102400"   
## [11] "12" "365" "26280" "52560" "2920"   
## [16] "262800" "105120" "0.1" "87600" "3"   
## [21] "0.5" "52" "6" "0.2" "175200"   
## [26] "26" "730" "1"

#check to make sure all frequencies were quantified  
  
oahfocus <- oahfocus[!is.na(oahfocus$Latitude), ]  
oahfocus <- oahfocus[!is.na(oahfocus$Longitude), ]  
#remove NA coordinates  
  
gsub(" ", "", oahfocus$Latitude)

## [1] "26.181" "26.09" "26.091"   
## [4] "25.92" "25.92" "25.75"   
## [7] "25.75" "25.59" "25.42"   
## [10] "28.44" "28.39" "28.39"   
## [13] "25.25" "25.25" "28.221"   
## [16] "28.22" "25.09" "25.09"   
## [19] "28.05" "28.05" "24.92"   
## [22] "27.851" "27.85" "27.79"   
## [25] "27.79" "27.72" "27.72"   
## [28] "27.55" "27.55" "27.39"   
## [31] "27.39" "27.22" "31.709"   
## [34] "31.69" "31.69" "31.62"   
## [37] "31.62" "31.521" "31.52"   
## [40] "32.6001" "32.5691" "32.5595"   
## [43] "32.536333" "32.471667" "32.5682"   
## [46] "32.54035" "32.553833" "32.513333"   
## [49] "32.594667" "32.471667" "32.54057"   
## [52] "32.556667" "32.5745" "32.55713"   
## [55] "32.561167" "32.5393" "32.639167"   
## [58] "32.516667" "32.55748" "32.536167"   
## [61] "32.4935" "32.550833" "32.572333"   
## [64] "32.467" "32.55782" "32.5955"   
## [67] "32.54" "32.537833" "32.511667"   
## [70] "32.636667" "32.532833" "32.537833"   
## [73] "32.543" "32.553333" "32.668833"   
## [76] "32.537833" "32.574167" "32.55742"   
## [79] "32.54047" "32.595333" "32.473333"   
## [82] "32.516667" "32.55743" "32.5375"   
## [85] "32.63" "32.648" "32.5945"   
## [88] "32.560667" "32.66637" "32.6842"   
## [91] "32.65633" "32.6474" "32.62038"   
## [94] "32.623833" "32.53975" "32.637683"   
## [97] "32.66388" "32.665833" "32.516667"   
## [100] "32.5574" "32.679167" "32.557"   
## [103] "32.8669" "32.67817" "32.693667"   
## [106] "32.659333" "32.593833" "32.7571"   
## [109] "32.6755" "32.594533" "32.611683"   
## [112] "32.692667" "32.716333" "32.781833"   
## [115] "32.756966" "32.732667" "32.630833"   
## [118] "32.9491" "32.75502" "32.473333"   
## [121] "32.651134" "32.85412" "32.67353"   
## [124] "32.67215" "32.68555" "32.5941"   
## [127] "32.7528" "32.611833" "32.705419"   
## [130] "32.630016" "32.725544" "32.649766"   
## [133] "32.746583" "32.6696" "32.9564"   
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## [139] "32.685416" "32.781559" "32.593766"   
## [142] "32.91889" "32.7038" "32.72273"   
## [145] "32.611783" "32.629287" "32.66558"   
## [148] "32.66567" "32.647815" "32.684668"   
## [151] "32.741883" "33.1141" "32.70833333"   
## [154] "32.701416" "32.761216" "33.139"   
## [157] "32.720466" "33.1123" "32.77895"   
## [160] "32.7389" "33.1106" "32.7577"   
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## [172] "33.1962" "33.1506" "33.1906"   
## [175] "33.1852" "32.81666667" "33.2253"   
## [178] "33.1796" "33.2199" "33.1746"   
## [181] "33.2145" "31.449" "31.35"   
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## [187] "32.8464" "32.91666667" "33.4946"   
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## [205] "33.49715" "32.6797" "33.4809"   
## [208] "33.58892" "33.46466" "33.57925"   
## [211] "33.57608" "33.44842" "33.55982"   
## [214] "33.59618" "33.43218" "33.58805"   
## [217] "33.54355" "33.418" "33.41795"   
## [220] "33.57993" "33.52745" "33.56352"   
## [223] "33.54752" "33.60305" "33.60208"   
## [226] "33.53167" "33.59385" "33.58482"   
## [229] "33.61462" "33.60453" "33.56998"   
## [232] "33.59502" "33.62488" "33.55515"   
## [235] "33.61502" "33.58018" "33.60522"   
## [238] "33.54033" "33.63498" "33.56537"   
## [241] "33.62537" "33.57222" "33.57272"   
## [244] "33.59038" "33.61557" "33.55053"   
## [247] "33.64287" "33.57557" "33.63422"   
## [250] "33.60058" "33.57722" "33.62562"   
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## [304] "33.66953" "33.65042" "33.63131"   
## [307] "33.6122" "33.70288" "33.69327"   
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## [367] "30.85" "32.71666667" "33.87945"   
## [370] "33.9011" "33.84" "33.92776"   
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## [382] "33.8895" "33.8111" "33.86833"   
## [385] "33.91666" "33.98" "33.88721"   
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## [400] "33.78" "34.03333" "34.02583"   
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## [415] "34.01943" "34.0275" "33.94276"   
## [418] "33.96026" "33.9975" "33.93"   
## [421] "32.71666667" "30.686" "30.69"   
## [424] "33.99527" "33.9125" "33.92805"   
## [427] "33.95833" "33.98055" "33.98833"   
## [430] "34.0214" "33.79" "33.64"   
## [433] "32.1797" "34.03544" "34.02571"   
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## [472] "34.23065" "34.13992" "34.22732"   
## [475] "33.68999837" "33.44" "34.22166"   
## [478] "34.12876" "34.27123" "34.21452"   
## [481] "33" "34.2651" "34.2635"   
## [484] "34.11839" "34.20637" "34.25557"   
## [487] "34.017" "34.0164" "34.24853"   
## [490] "34.19531" "34.24054" "34.2251"   
## [493] "34.23303" "33.58666585" "30.35"   
## [496] "32.6513" "34.1784" "34.045516666666664"  
## [499] "31.8464" "33.48666585" "33.3229"   
## [502] "34.0204" "34.40934" "34.39323"   
## [505] "33.2" "33.38333333" "34.4056"   
## [508] "34.40685962" "32.418" "33.1"   
## [511] "32.39" "33.1562" "34.2749"   
## [514] "32.34" "32.35" "34.46495"   
## [517] "33.8784" "31.513" "34.46713695"   
## [520] "34.4617" "34.31833496" "32.94"   
## [523] "34.057" "32.9895" "33.7451"   
## [526] "34.43" "34.17666829" "34.4667"   
## [529] "34.43" "34.45" "34.44"   
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## [544] "35" "35.04" "33.5784"   
## [547] "35.0882" "34.31" "35"   
## [550] "34.33" "34.3167" "35"   
## [553] "34.324" "35.370933" "35"   
## [556] "31.95" "31.95" "35.0216"   
## [559] "31.1797" "34.94" "35"   
## [562] "32.6" "34.21" "34.21"   
## [565] "32.6562" "34.87" "35.54030478"   
## [568] "35" "34.15" "34.139"   
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## [574] "35.6438" "31.7513" "35.70333252"   
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## [580] "35.70333252" "34.67" "34.7216"   
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## [592] "36.8179" "36.824" "36.8398"   
## [595] "36.8423" "36.8439" "36.8457"   
## [598] "36.8471" "36.8563" "36.8565"   
## [601] "36.8247" "36.8111" "36.8111"   
## [604] "36.7963" "36.8215" "36.8"   
## [607] "36.7997" "36.7908" "36.8209"   
## [610] "36.8025" "36.81" "33.8167"   
## [613] "36.795" "36.8" "36.8"   
## [616] "34.5" "35.70333252" "36.76666667"   
## [619] "36.8" "36.79" "36.78"   
## [622] "36.784" "36.60513" "36.70833333"   
## [625] "36.62" "36.758" "36.76"   
## [628] "36.76" "36.3" "36.65500081"   
## [631] "35.3105" "36.737" "36.74"   
## [634] "36.73" "36.73999837" "36.84666748"   
## [637] "31.418" "36.0487" "38.1841"   
## [640] "36.3" "36.73" "36.71"   
## [643] "36.71" "36.713" "36.96049"   
## [646] "36.75" "38.1949" "36.58333333"   
## [649] "36.64666748" "36.787" "36.7"   
## [652] "36.69" "36.69" "36.695"   
## [655] "36.3" "45.60058" "36.7"   
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## [2107] "-130.373" "-130.63" "-130.632"   
## [2110] "-130.876" "-130.88" "-131.54"   
## [2113] "-132.18" "-132.82"

oahfocus$Longitude<-as.numeric(oahfocus$Longitude)  
oahfocus$Latitude<-as.numeric(oahfocus$Latitude)  
#remove spaces and transform to numeric  
  
carbcomplete<-subset(oahfocus, DisCrbPmtr>1 | ISCrbPmtr > 1)  
incomplete <- subset(oahfocus, DisCrbPmtr<2 & ISCrbPmtr < 2)  
highfrequency<-subset(oahfocus, MeasFreq > 364)  
highfreqcarbcomplete<-subset(oahfocus, MeasFreq > 364 & DisCrbPmtr>1 | MeasFreq > 364 & ISCrbPmtr > 1)  
lowfrequency <- subset(oahfocus, MeasFreq < 365)  
#subset data

#### Transform into spatial data

coords <- cbind.data.frame(oahfocus$Longitude, oahfocus$Latitude) #isolate coordinate columns  
  
deduped.coords<-unique(coords) # remove duplicate locations  
  
inventorycoords <- SpatialPoints(deduped.coords, CRS("+proj=longlat +ellps=WGS84"))  
inventorycoords <- spTransform(inventorycoords, CRS('+init=EPSG:6414')) # create spatial points objects  
  
# isolate coordinate columns  
coords <- cbind.data.frame(oahfocus$Longitude, oahfocus$Latitude)  
carbcompletecoords <- cbind.data.frame(carbcomplete$Longitude, carbcomplete$Latitude)  
incompletecoords <- cbind.data.frame(incomplete$Longitude, incomplete$Latitude)  
highfrequencycoords <- cbind.data.frame(highfrequency$Longitude, highfrequency$Latitude)  
lowfrequencycoords <- cbind.data.frame(lowfrequency$Longitude, lowfrequency$Latitude)  
highfreqcarbcompletecoords <- cbind.data.frame(highfreqcarbcomplete$Longitude, highfreqcarbcomplete$Latitude)  
  
# remove duplicate locations  
deduped.coords<-unique(coords)  
deduped.carbcomplete <- unique(carbcompletecoords)  
deduped.incomplete <- unique(incompletecoords)  
deduped.highfrequency <- unique(highfrequencycoords)  
deduped.lowfrequency <- unique(lowfrequencycoords)  
deduped.highfreqcarbcomplete <- unique(highfreqcarbcompletecoords)  
  
# create spatial points objects  
inventorycoords <- SpatialPoints(deduped.coords, CRS("+proj=longlat +ellps=WGS84"))  
inventorycoords <- spTransform(inventorycoords, CRS('+init=EPSG:6414'))  
  
carbcompletecoords <- SpatialPoints(deduped.carbcomplete, CRS("+proj=longlat +ellps=WGS84"))  
carbcompletecoords <- spTransform(carbcompletecoords, CRS('+init=EPSG:6414'))  
  
incompletecoords <- SpatialPoints(deduped.incomplete, CRS("+proj=longlat +ellps=WGS84"))  
incompletecoords <- spTransform(incompletecoords, CRS('+init=EPSG:6414'))  
  
highfreqcoords <- SpatialPoints(deduped.highfrequency, CRS("+proj=longlat +ellps=WGS84"))  
highfreqcoords <- spTransform(highfreqcoords, CRS('+init=EPSG:6414'))  
  
lowfreqcoords <- SpatialPoints(deduped.lowfrequency, CRS("+proj=longlat +ellps=WGS84"))  
lowfreqcoords <- spTransform(lowfreqcoords, CRS('+init=EPSG:6414'))

#### Create voronoi polygons

vor <-voronoi(inventorycoords)  
  
vorraster<- rasterize(vor, r\_sst\_mean, "id") #rasterize

#### Extract SST mean and range for each monitoring site cell and substitute value for each voronoi polygon

sitesst<- raster::extract(r\_sst\_mean, inventorycoords, method='simple', df=TRUE)  
colnames(sitesst)<-c("id", "SST") #rename column names of sitesst  
polygonsst <- subs(vorraster, sitesst, by="id", which="SST", subsWithNA=FALSE) #substitute polygon id for monitoring site sea surface temerature of that polygon  
  
sitesstrange<- raster::extract(r\_sst\_range, inventorycoords, method='simple', df=TRUE)  
colnames(sitesstrange)<-c("id", "SSTrange") #rename column names of sitesstrange  
polygonsstrange<-subs(vorraster, sitesstrange, by="id", which="SSTrange", subsWithNA=FALSE) #substitute polygon id for monitoring site sea surface temerature range of that polygon

#### Repeat with DO

sitedo<- raster::extract(r\_do\_mean, inventorycoords, method='simple', df=TRUE)  
colnames(sitedo)<-c("id", "DO") #rename column names of sitedo  
polygondo<-subs(vorraster, sitedo, by="id", which="DO")  
  
sitedorange<- raster::extract(r\_do\_range, inventorycoords, method='simple', df=TRUE)  
colnames(sitedorange)<-c("id", "DOrange")  
polygondorange<-subs(vorraster, sitedorange, by="id", which="DOrange")

## Step 3. Create “oceanographic variability” layer relative to monitoring asset

To account for variation in both SST and DO as a combined proxy for ocean acidification variability, we use the following formula: variation = (imean - amean) + (imean - amean)\*(irange - arange) where i = cell in raster of study area and a = cell containing nearest monitoring site

sstmeandiff <- abs(r\_sst\_mean\_nofill - polygonsst) #difference between sst at each point and sst for area associated with closest monitoring site  
sstrangediff <- abs(r\_sst\_range\_nofill - polygonsstrange) #difference between sst range at each point and sst range for area associated with closest monitoring site   
sstvariation <- sstmeandiff+(sstmeandiff\*sstrangediff)  
  
domeandiff <- abs(r\_do\_mean\_nofill - polygondo) #difference between DO at each point and DO for area associated with closest monitoring site  
dorangediff <- abs(r\_do\_range\_nofill - polygondorange) #difference between DO range at each point and DO range for area associated with closest monitoring site  
dovariation <- domeandiff + (domeandiff\*dorangediff)  
  
variation <- (sstvariation\*dovariation) #total variation

## Step 4. Identify gaps

#### Identify gaps based on distance between monitoring points, qualified by strength of variability

distance<-distanceFromPoints(variation,inventorycoords)  
gaps <- setValues(distance, log10(getValues(distance)\*(getValues(variation))))

#### Visualize gaps along the West Coast

#poly\_coast<- readOGR(dsn=path.expand("/Users/Madi/Documents/UCSB  
#Bren/ResilienSeas/Export\_Output\_2"), layer="Export\_Output\_2")  
#poly\_coast <- spTransform(poly\_coast, crs(gaps))  
#gaps\_clipped <- mask(gaps, poly\_coast, inverse = TRUE,progress='text')