The Coastal Processes of Flinders Beach and their Management Implications

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1. Introduction

Coastal processes are the complex ever dynamic interactions between sediment, waves, and wind, and even gravity (Wright and Short 1984). Beaches are especially complex systems as they are almost never stable systems. The rise and fall of the tide changes where the water starts and beach ends on an hourly basis and the wave patterns and sediment transport can determine that beach's size on the decadal scale (Wright and Short 1984). All of this is made more complicated by the simple fact that humans like beaches and often like to build homes and other structures near them. However, without good understanding of the coastal processes that drive the structure of beaches, developing coastal areas can expose those developments to unforeseen risk and hazards (Kousky 2014). This report will discuss the coastal processes of Finders Beach on Minjerribah – North Stradbroke Island and their potential management implications. Using wave data, shoreline profiles, and visual surveys this report will examine the underlying geomorphology of the beach, the processes that drive that morphology, the effect climate change and rising sea levels might have, and the management implications of developing land near the beach.

2. Regional Setting

Flinders Beach located on the northern side of Minjerribah - North Stradbroke Island shown in Figure 1. The beach sits in between the headland of Adder Rock and northern most point of the island, Amity Point. Flinders Beach is partially embayed by the headland of Adder Rock on its eastern side but lacks any such outcrop on its western edge. Minjerribah – North Stradbroke Island consists primarily of sand deposits and is the second largest sand island in the world (Gontz, Moss, and Wagenknecht 2013). It is approximately 35km in length and exists in a subtropical climate with a hot, wet summer season and mild, dry winter season (Thompson 1992).

Figure 1. Location of Flinders Beach and the Brisbane wave buoy in relation to their geographic surroundings.

3. Methods

Data management, analysis, and visualization for this report was conducted in R. The appendix contains text of the R scripts used but the scripts and data used can also be found in this GitHub repository: https://github.com/jwilkensWes/flinders_report. A visual analysis using satellite and field imagery was conducted to determine beach type. To determine wave climate, data was collected from the Brisbane wave buoy (location shown in Fig. 1) over the time period of 1996 to 2018. The Brisbane buoy was chosen for its proximity to Flinders Beach, however, the beach is located on the northern side of the island while the buoy is located off its eastern shore. The buoy data therefore must be assumed to be not fully representative of wave conditions closer to Flinders Beach. Histograms of wave direction and significant wave height were created in R and because the distribution of wave height matched a Rayleigh Distribution, equation 1 was used to calculate significant wave height exceedance values (Longuet-Higgins 1953). Where Q is the probability of exceedance and σ is the standard deviation of significant wave height.

(1)

$$H_Q = 2\sigma\sqrt{2\ln\left(\frac{1}{Q}\right)}$$

Historical shoreline position data was collected from the Digital Earth Australia Coastlines website (Geoscience Australia, n.d.). This data was then visualized in a scatter plot to show trends in shoreline position. Mean wave height was then plotted against shoreline position to investigate any correlations between the two. A simple linear regression was conducted (position ~ mean wave height) to determine if any observed correlations exhibited statistical significance. Retreat forecasts were created by calculating the mean significant wave height ($\overline{H_s}$) and standard deviation of wave height (σ) from the wave buoy data mentioned previously. These values were used to calculate the profile closure depth (h_c) in equation 2.

(2)

$$h_c = 2\overline{H_s} + 11\sigma$$

The profile closure depth was then used in conjunction with the Brunn Rule (Bruun 1962) to calculate an estimate of shoreline retreat as a result of sea level rise. Equation 3 shows this where R_{sl} is shoreline retreat due to sea level rise, S is sea level rise, L is the cross-shore length of beach, and b is berm height. L and b were determined from an inspection of the shoreline profile (fig. 6). Sea level rise levels were sourced from the Canute 3.0 sea level calculator. Profile closure depth and the Brunn Rule were chosen to model shoreline retreat because of their widespread use in the literature (Cooper and Pilkey 2004). However, it requires limiting assumptions to ensure its validity and limits its predictive power (Cooper and Pilkey 2004). An estimate of retreat due to shoreline fluctuations was also calculated according to equation 4 where sce is the shoreline change envelope. These values were used with QGIS' 'one-sided-buffer tool' to create polygons visualizing what the shoreline retreat would look like. All GIS maps were created using the MGA zone 56 coordinate reference system.

(3)

$$R_{sl} = S\left(\frac{L}{b + h_c}\right)$$

(4)

$$R_f = \frac{sce}{2}$$

4. Results

Flinders Beach is a intermediate transverse bar and trough type beach. Figures 2 shows a histogram of wave direction at the Brisbane wave buoy. The data is mostly concentrated between $90°$ and $180°$ with a small amount around $20°$. Figure 3 shows a histogram of significant wave height measured in meters. The data resembles a Rayleigh Distribution and is concentrated between 1 and 2 meters with a tail extending to the right. Wave height exceedance values are as follows: $H_{0.5} = 1.67m$, $H_{0.1} = 3.04m$, $H_{0.01} = 4.30m$. The historical shoreline of Flinders Beach has exhibited a large amount of variability over the historical record available. Most notably, figure 4 shows a large increase in shoreline position between 2002 and 2003. Upon visual inspection of figure 5 it appears that there is a slightly negative correlation between wave height and shoreline position, however the linear model of the two variables shows a p-value of 0.12. The profile closure depth was calculated to be 11.09 meters with a mean significant wave height of 1.65m and 0.71m standard deviation. With a berm height of 3.6m this translates to a cross shore length of approximately 1375 meters. R_{sl} then equals ~21m for 2050 and ~72m for 2100. R_f equals ~35m. These distances are modeled on figure 7.

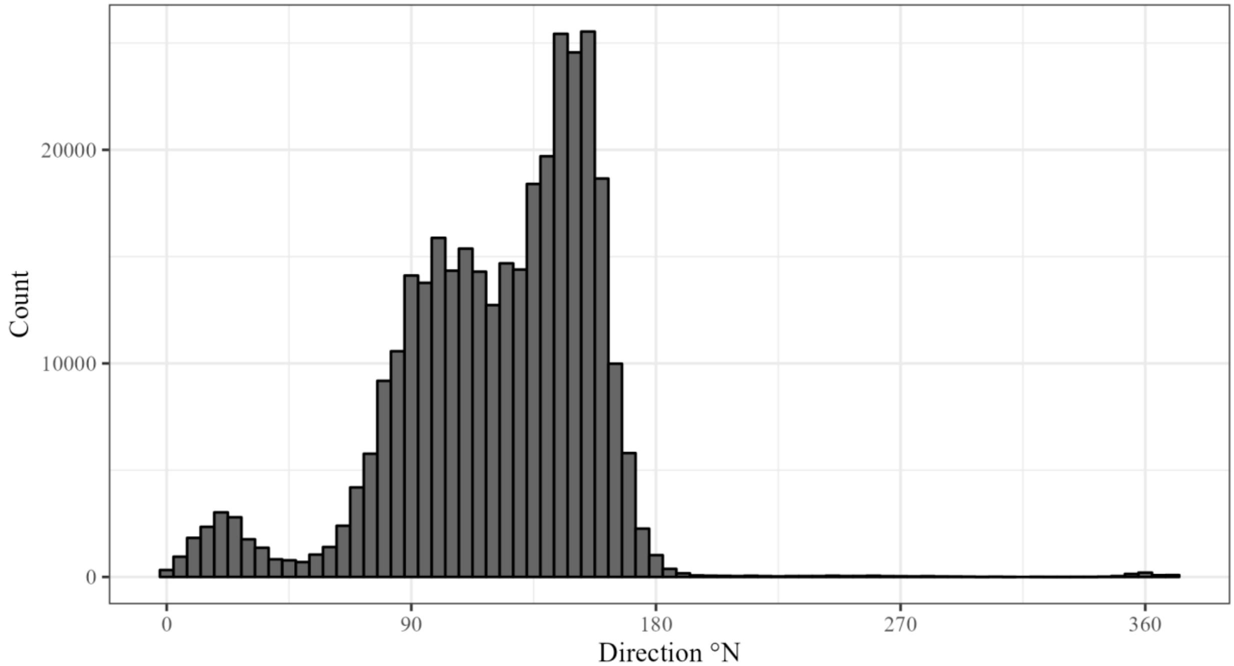

Figure 2. Wave direction as measured by the Brisbane Wave Buoy from 1996 to 2018.

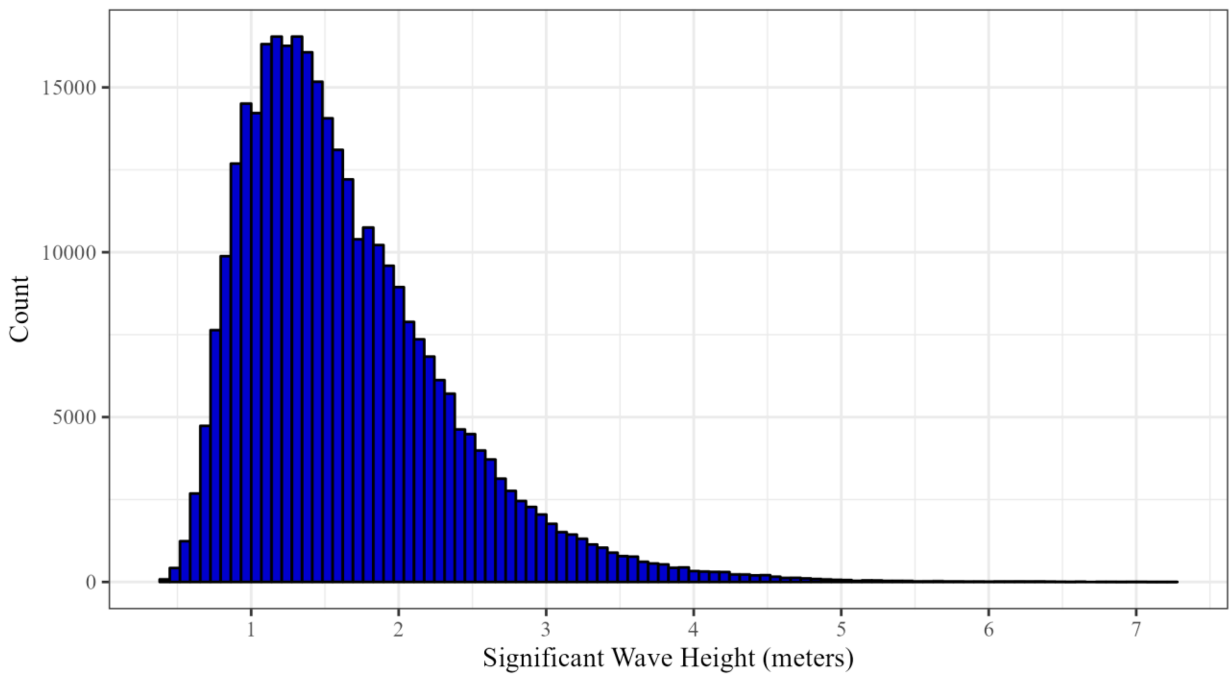

Figure 2. Significant wave height as measured by the Brisbane Wave Buoy from 1996 to 2018.

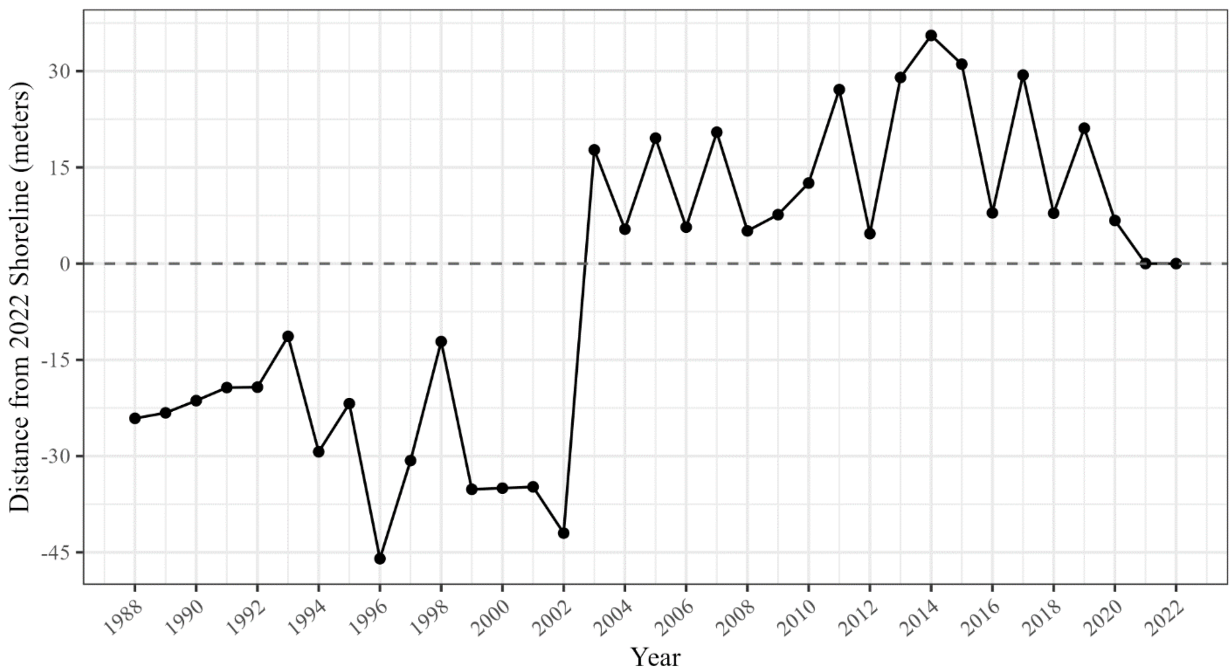

Figure 4. Shoreline position of Flinders Beach measured in meters from the 2022 shoreline (Geoscience Australia, n.d.).

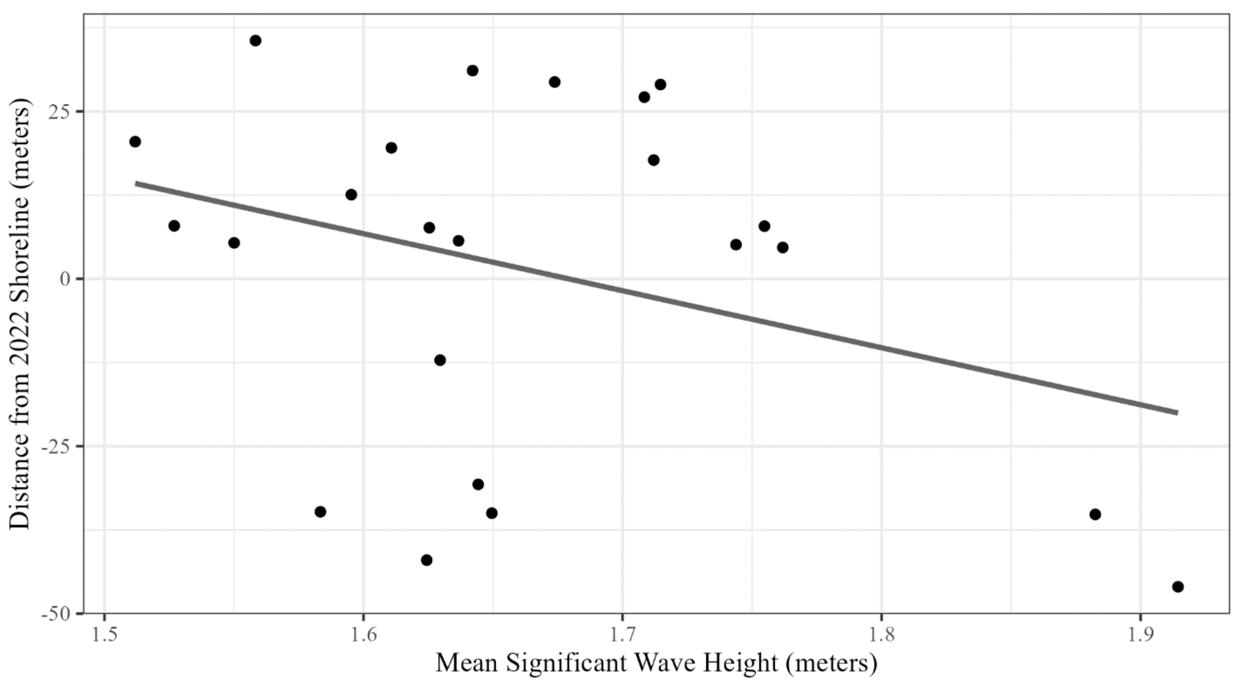

Figure 5. Mean significant wave height plotted against shoreline position with a line of best fit added.

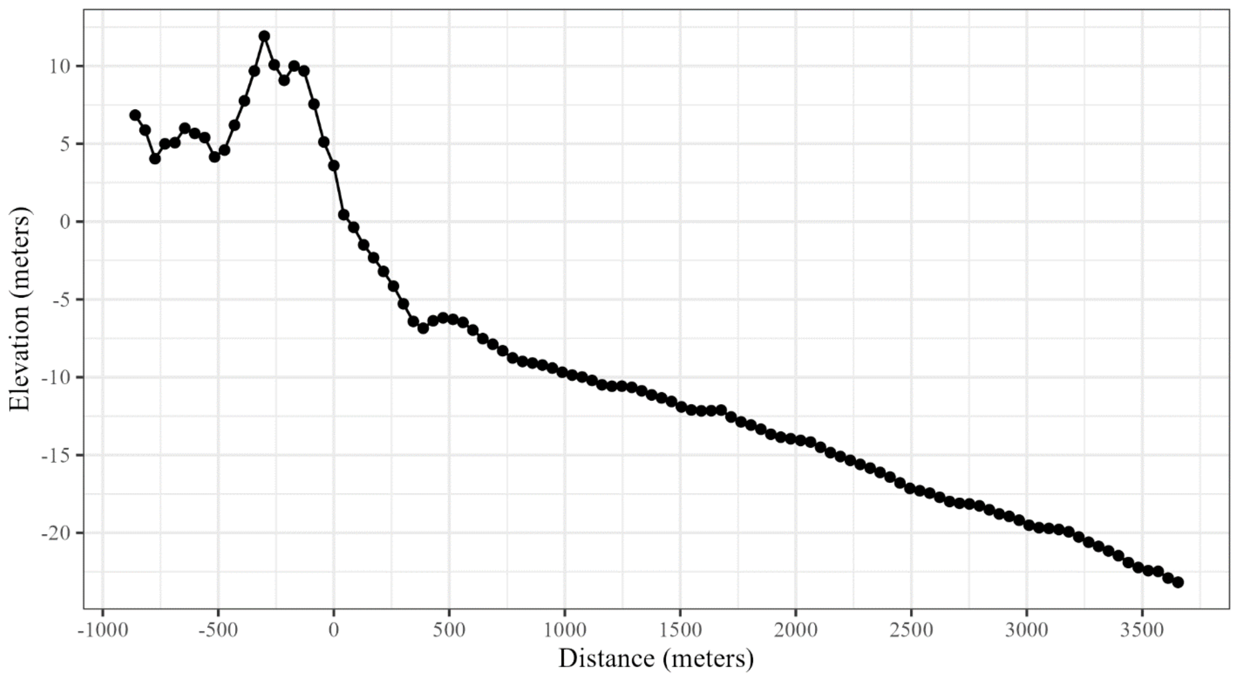

Figure 6. Shoreline profile of Flinders Beach.

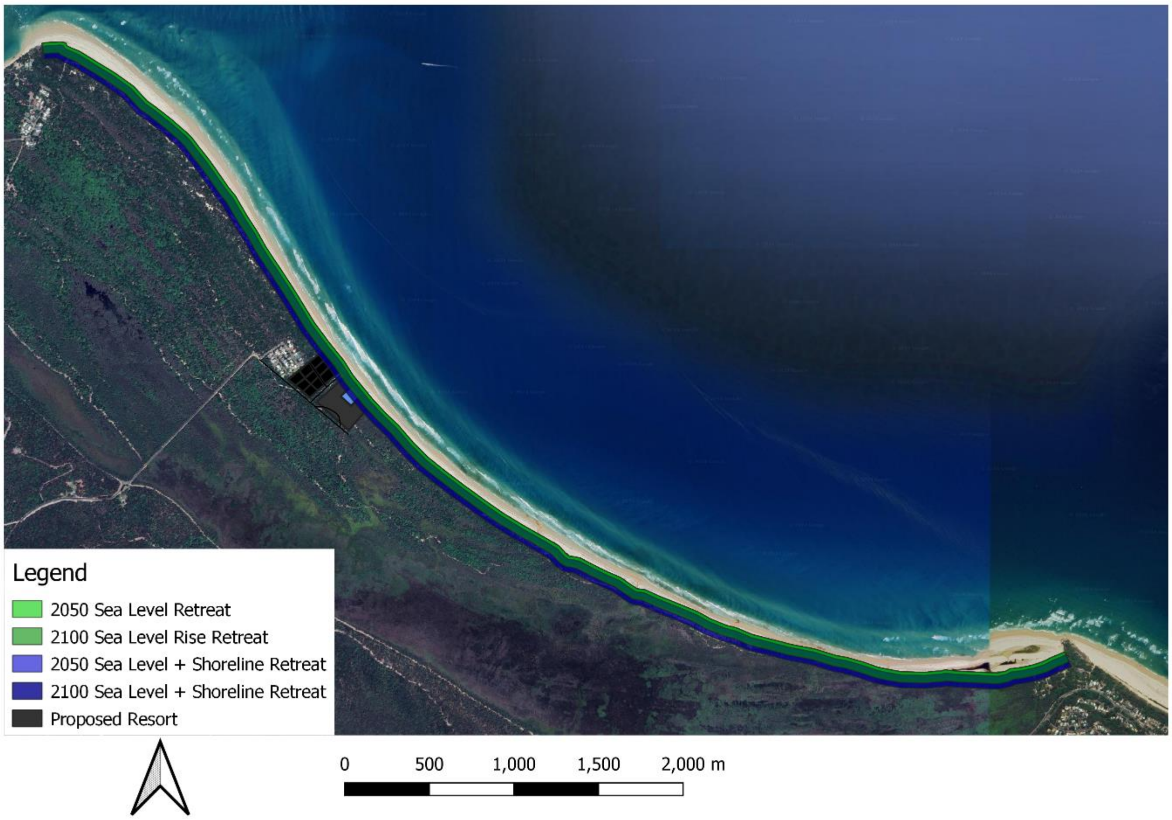

Figure 7. Modeled shoreline retreat for 2050 and 2100 using sea level rise and shoreline fluctuation.

5. Discussion

Flinders Beach is a highly variable coastal environment. As a transvers bar and trough beach Flinders is theoretically subject to a high degree of mobility (Wright and Short 1984) which is born out in the data. Figure 4 shows significant year to year fluctuations in shoreline position with the direction of variation reversing almost annually. The primarily south-easterly direction of the wave climate implies a strong longshore transport effect where sediment is moved from more southern locations up the coast by waves (van Rijn 2014). Flinders Beach's shoreline position is most likely driven by headland bypassing. Headland bypassing is the passage of sediment around a rocky headland at intermittent intervals (Klein et al. 2020). Sediment builds up behind the headland until it is released as a result of a storm event or from too much accretion (Silva et al. 2021). Flinders Beach is likely influenced by two major headlands; the Adder rock headland that sits on its eastern edge of the beach in addition to the Point Lookout headland that occupies the eastern most point of the island. The large increase in shoreline position seen in figure 4 is most likely the result headland bypassing as there is no easily accessible record of human driven management (i.e. beach nourishment). Since the linear model relating shoreline position and mean wave height returned a p-value of only 0.12 it is unlikely that the direct interaction between waves and the beach drive the position of the shoreline. The shoreline retreat visualizations (fig. 7) show the shoreline will likely shift backwards over time, but that the shoreline fluctuation may play a large role in determining the magnitude of that shift. The shoreline retreat directly threatens the proposed resort development and, according to the preliminary research of this study, would by 2050 be experiencing erosive effects due to shoreline retreat. The most effective management strategy to reduce risk would be to prevent the development of such a resort at all. However, in lieu of such a policy a seawall could protect the property from erosion. Unfortunately the such a sea wall would likely result in the loss of beach width and other ecosystem services as the sea levels rise to meet wall and deprive the resort of their primary economic driver (Kousky 2014). However recent evidence suggests suggest that beaches experiencing long-term accretion (such as Flinders Beach) may have a net-positive sediment budget as a result of changes in global tropical climates (Cowley et al. 2022). Therefore, the shoreline fluctuation component used in this study may work in the opposite direction and provide a buffer against sea level rise. This report finds that Flinders Beach is a highly variable coastal environment subject significant changes to its dimensions both historically and into the modeled future. Because of that variability, it is deemed unwise to construct new developments close to the shoreline and any construction should only occur around 100 meters behind the existing shoreline to reduce risk in the next century.

6. References

Bruun, Per. 1962. “Sea-Level Rise as a Cause of Shore Erosion.” *Journal of the Waterways and Harbors Division* 88 (1): 117–30. https://doi.org/10.1061/JWHEAU.0000252.

Cooper, J. Andrew G., and Orrin H. Pilkey. 2004. “Sea-Level Rise and Shoreline Retreat: Time to Abandon the Bruun Rule.” *Global and Planetary Change* 43 (3): 157–71. https://doi.org/10.1016/j.gloplacha.2004.07.001.

Cowley, D., D. L. Harris, P. T. Moss, and J. Shulmeister. 2022. “Beach Narrowing on Prograding Coasts: Examples from the Tropics to Subtropics of Eastern Australia.” *Geomorphology* 401 (March):108110. https://doi.org/10.1016/j.geomorph.2022.108110.

Geoscience Australia. n.d. Digital Earth Australia Coastlines. Accessed May 17, 2024. https://maps.dea.ga.gov.au/story/DEACoastlines.

Gontz, Allen M., Patrick T. Moss, and Ekatherina K. Wagenknecht. 2013. “Stratigraphic Architecture of a Regressive Strand Plain, Flinders Beach, North Stradbroke Island, Queensland, Australia.” *Journal of Coastal Research* 30 (3): 575–85. https://doi.org/10.2112/JCOASTRES-D-12-00234.1.

Klein, Antonio H. F., Guilherme Vieira da Silva, Rui Taborda, Ana P. da Silva, and Andrew D. Short. 2020. “23 - Headland Bypassing and Overpassing: Form, Processes and Applications.” In *Sandy Beach Morphodynamics*, edited by Derek W. T. Jackson and Andrew D. Short, 557–91. Elsevier. https://doi.org/10.1016/B978-0-08-102927-5.00023-0.

Kousky, Carolyn. 2014. “Managing Shoreline Retreat: A US Perspective.” *Climatic Change* 124 (1): 9–20. https://doi.org/10.1007/s10584-014-1106-3.

Longuet-Higgins, M. 1953. “On the Statistical Distribution of the Heights of Sea Waves.” *Journal of Marine Research* 11 (3). https://elischolar.library.yale.edu/journal_of_marine_research/774.

Rijn, Leo C. van. 2014. “A Simple General Expression for Longshore Transport of Sand, Gravel and Shingle.” *Coastal Engineering* 90 (August):23–39. https://doi.org/10.1016/j.coastaleng.2014.04.008.

Silva, Ana Paula da, Guilherme Vieira da Silva, Darrell Strauss, Thomas Murray, Lorena G. Woortmann, Jonathan Taber, Nick Cartwright, and Rodger Tomlinson. 2021. “Headland Bypassing Timescales: Processes and Driving Forces.” *Science of The Total Environment* 793 (November):148591. https://doi.org/10.1016/j.scitotenv.2021.148591.

Thompson, C. H. 1992. “Genesis of Podzols on Coastal Dunes in Southern Queensland .I. Field Relationships and Profile Morphology.” *Soil Research* 30 (5): 593–613. https://doi.org/10.1071/sr9920593.

Wright, L. D, and A. D Short. 1984. “Morphodynamic Variability of Surf Zones and Beaches: A Synthesis.” *Marine Geology* 56 (1): 93–118. https://doi.org/10.1016/0025-3227(84)90008-2.

7. Appendix

7.1 Data Management

```
# Data Management

# packages
library(readr)
library(readxl)
library(dplyr)
library(lubridate)


# shoreline history from Digital Earth Australia Coastlines
flshore <-
read_csv("data/rawdata/deaflindersbeachhistoricalshoreline.csv")
## convert to lowercase

flshore$year <- flshore$Year
flshore$distance <- flshore$`Distance (m)`
flshore$Year <- NULL
flshore$`Distance (m)`<- NULL

## save file
save(flshore, file = "data/cleandata/flshore_hist.Rdata")


# beach profile
flprofile <- read_excel("data/rawdata/Flinders_Profile.xlsx")

## convert to lowercase
flprofile$distance <- flprofile$Distance
flprofile$Distance <- NULL
flprofile$elevation <- flprofile$Elevation
flprofile$Elevation <- NULL
flprofile

## save file
save(flprofile, file = "data/cleandata/flprofile.Rdata")


# wave data
flwave <- read_excel("data/rawdata/bris_waves_cleaned.xlsx")

## add directions as cats
flwave <- flwave %>% mutate(compass = case_when(
  dir > 0 & dir < 90 ~ "NE",
  dir > 90 & dir < 180 ~ "SE",
```

```
  dir > 180 & dir < 270 ~ "SW",
  dir > 270 ~ "NW"
))

## make year column
flwave$year <- NULL
flwave <- flwave %>% mutate(year = year(time))

## save file
save(flwave, file = "data/cleandata/flwave.Rdata")


# grain size data
flgrain <-
read_csv("data/rawdata/MARS_Grain_size_distribution_20240514_120409.cs
v")

## rename columns correctly
gnames <- as.character(flgrain[1,])
flgrain <- flgrain %>% slice(-1)
colnames(flgrain) <- gnames

## cleaning
keep_columns <- c("SURVEY ID", "SAMPLE NO", "SAMPLE TYPE", "SAMPLE
COMMENTS",
                  "WATER DEPTH", "PROPERTY", "QUALIFIER", "NUM VALUE",
"UOM", "COMMENTS")
flgrain <- flgrain[, keep_columns]
flgrain <- flgrain %>% filter(startsWith(flgrain$QUALIFIER, "geometric
mean"))
flgrain$numval <- as.numeric(flgrain$`NUM VALUE`)

## save
save(flgrain, file = "data/cleandata/flgrain.Rdata")
```

7.2 Calculations

```
# calculations

# packages
library(dplyr)

# data
load("data/cleandata/flwave.Rdata")
load("data/cleandata/flgrain.Rdata")


# hi calc, wave impact on sediment transport

## significant wave height average, 1.647 meters
```

```
hs_avg <- as.numeric(flwave %>% summarize(avg = mean(hsig)))
save(hs_avg, file = "data/cleandata/hs_avg.Rdata")

## significant wave height standard deviation, 0.709, meters
hs_stdv <- as.numeric(flwave %>% summarize(stdev = sd(hsig)))
save(hs_stdv, file = "data/cleandata/hs_stdv.Rdata")

## mean significant wave period, 6.334 secs
ts_avg <- as.numeric(flwave %>% summarize(avg = mean(tz)))

## grain size mean, 0.000238 meters
gsize_avg <- as.numeric(flgrain %>% summarize(avg = mean(numval))) /
1000

## the depth at which waves have an impact of sediment transport:
26.090 meters
hi <- (hs_avg - 0.3 * hs_stdv) * ts_avg * sqrt(9.8 / (5000 *
gsize_avg))


# hc calc, profile closure depth

## profile closure depth: 11.094 meters
hc <- (2 * hs_avg + 11 * hs_stdv)
save(hc, file = "data/cleandata/profileclosuredepth.Rdata")
```

7.3 Data Visualization

```
# data visualization

# packages
library(ggplot2)
library(dplyr)
library(ggpubr)

# data sets
load("data/cleandata/flwave.Rdata")
load("data/cleandata/flshore_hist.Rdata")
load("data/cleandata/flprofile.Rdata")
load("data/cleandata/profileclosuredepth.Rdata")


# wave height and shoreline movement
## shoreline history

ggplot(flshore, aes(year, distance)) +
  geom_line() +
  geom_point() +
  scale_x_continuous(breaks = seq(min(flshore$year),
max(flshore$year), 2),
```

```
                     guide = guide_axis(angle = 40)) +
  scale_y_continuous(breaks = seq(-45, 35, 15)) +
  geom_hline(yintercept = 0, linetype = "dashed", color = "grey40") +
  theme_bw() +
  labs(x = "Year", y = "Distance from 2022 Shoreline (meters)") +
  theme(text = element_text(family = "serif"))

ggsave("reports/shoreline_history.png", scale = 2)

## wave direction
ggplot(flwave, aes(dir)) +
  geom_histogram(binwidth = 5, color = "black", fill = "grey40") +
  scale_x_continuous(breaks = seq(0, 360, 90)) +
  labs(x = "Direction \u00b0N", y = "Count") +
  theme_bw() +
  theme(text = element_text(family = "serif"))
  ### primarily south east wave direction
ggsave("reports/wave_direction.png", scale = 2)


## wave height
ggplot(flwave, aes(hsig)) +
  geom_histogram(bins = 100, color = "black", fill = "blue3") +
  labs(x = "Significant Wave Height (meters)", y = "Count") +
  scale_x_continuous(breaks = seq(0, 8, 1)) +
  theme_bw() +
  theme(text = element_text(family = "serif"))
### rayleigh distribution, right skewed
ggsave("reports/wave_height.png", scale = 2)

## create average wave height per year

flmeanwave <- flwave %>% group_by(year) %>%
  summarize(avg_wave_height = mean(hsig))

## plot avg wave height against shoreline position
flwaveshore <- flshore %>% full_join(flmeanwave)

ggplot(flwaveshore, aes(x = avg_wave_height, y = distance)) +
  geom_point() +
  geom_smooth(method = "lm", se = FALSE, color = "grey40") +
  theme_bw() +
  labs(x = "Mean Significant Wave Height (meters)",
       y = "Distance from 2022 Shoreline (meters)") +
  theme(text = element_text(family = "serif"))
ggsave("reports/wave_height_vs_shoreline.png", scale = 2)

md <- lm(distance ~ avg_wave_height, data = flwaveshore)
summary(md)

# shoreline profile
```

```
ggplot(flprofile, aes(distance, elevation)) +
  geom_line() +
  geom_point() +
  #geom_hline(yintercept = (-(hc)), linetype = "dashed", color =
"blue3") +
  #geom_vline(xintercept = 1375, linetype = "dashed", color = "blue3")
+
  labs(x = "Distance (meters)", y = "Elevation (meters)") +
  scale_x_continuous(breaks = seq(-1000, 4000, 500)) +
  scale_y_continuous(breaks = seq(-30, 15, 5)) +
  theme_bw() +
  theme(text = element_text(family = "serif"))
### cross shore profile is 1375 meters
### berm height is 3.6 meters
ggsave("reports/shoreline_profile.png", scale = 2)
```

7.4 Analysis

```
# Analysis, retreat forecasts and wave climate


# shoreline retreat forecast

## data points
load("data/cleandata/profileclosuredepth.Rdata")
sea_rise_100 <- 0.77 # meters, rcp 8.5 2100
sea_rise_50 <- 0.23 # meters, rcp 8.5 2050
cshore_length <- 1375 # meters
berm_height <- 3.6 # meters
rf <- 70.9/2 # meters

retreat_100 <- sea_rise_100 * (cshore_length / (berm_height + hc))
## 72.051
retreat_50 <- sea_rise_50 * (cshore_length / (berm_height + hc))
## 21.522
retreatflux_100 <- rf + retreat_100
## 107.501
retreatflux_50 <- rf + retreat_50
## 56.972


# wave climate

## data points
load("data/cleandata/flwave.Rdata")
load("data/cleandata/hs_avg.Rdata")
load("data/cleandata/hs_stdv.Rdata")

## exceedance calculation
h0.5 <- 2 * hs_stdv * sqrt(2 * log(1 / 0.5 ))
```

```
### 1.670 meters
h0.1 <- 2 * hs_stdv * sqrt(2 * log(1 / 0.1 ))
### 3.044 meters
h0.01 <- 2 * hs_stdv * sqrt(2 * log(1 / 0.01 ))
### 4.304 meters
```