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**Declaration**

I declare that this assignment is my own work and does not involve plagiarism or collusion. The sources of other people's work have been appropriately referenced, failing which I am willing to accept the necessary disciplinary action(s) to be taken against me.

Student's Signature :

Date of Submission:

## **Chapter 1: Introduction**

- 1.1 General Background
- 1.2 Rationale
- 1.3 Research Questions
- 1.4 Thesis statement
- 1.5 Scope of research
- 1.6 Significance of research
- 1.7 Limitations
- 1.8 Methodology

## **Chapter 2: Literature Review**

- 2.1 Bruun Rule
- 2.2 Rising sea levels
- 2.3 Extreme weather
- 2.4 Perceptions of coasts

### **1.1 General Background**

Over the years, coastal protection has become an extremely pertinent issue in many countries with cities located near the coast. Global warming and climate change has sped up the process of rising sea levels, it has exacerbated problems of coastal erosion in small island countries such as the Maldives and Kiribati. This is also applicable for Singapore, an island-nation with one of the smallest land areas in the world. Coastal protection has hence been one of the government's top priorities in recent years, and the government agency PUB was appointed to pilot the effort in coastal protection. In 2020, the government announced a coastal protection fund to help protect Singapore against rising sea levels. The amount of money injected into the fund in 2020 amounted to S\$5b, with more money being planned to be channeled into the fund whenever the fiscal situation allows for it.

Singapore's ongoing efforts to defend coastal areas from erosion include the construction of walls and stone embankments that covers 70 percent to 80 percent of Singapore's coastline. The rest are natural areas such as beaches and mangroves. Coastal engineering (hard

engineering) as well as soft engineering solutions have been used interchangeably and are being planned to be used to tackle this problem. As recently as 2021, the government announced the 2030 green plan, which plans to fortify and build coastal defences along the City-East Coast stretch. East Coast Park, the main focus of this research paper, is a recreational park with various activities to cater to locals as well as tourists visiting the country. It lies along the southeastern coast of Singapore and sits on entirely reclaimed land, with the shoreline mainly composed of sandy shorelines. (Deltares, 2013). It attracts a significant 7 million visitors per year, proving itself as a popular urban getaway destination for locals seeking some relaxation. There are also around 48,000 people living in the Marine Parade Area, (Singstat, 2020) which justifies the need to protect these coastal areas to protect people living near them.

## **1.2 Rationale**

This research paper focuses on coastal erosion in East Coast Park. With polar ice caps melting at an unprecedented rate, sea level rise and its consequences are becoming an existential threat for many countries as well as Singapore, It is important to understand the effects of this sea level rise and how it affects coastal erosion processes in Singapore. In recent years, some unexpected erosion phenomena have also been observed. A more comprehensive understanding would allow for more effective and efficacious measures that can be implemented to counter and combat the threat of sea level rise.

## **1.3 Research questions**

1. How vulnerable is East Coast Park to rising sea levels driven by climate change and rising sea levels?
2. How do different types of weather phenomena affect the coast?
3. How do Singaporeans value coasts?

#### **1.4 Thesis statement**

Due to climate change causing sea level rise and more extreme weather patterns, the measures adopted at East Coast Park may not be sufficient to protect it from coastal erosion.

#### **1.5 Scope/Delimitations**

This research will be limited to East Coast Park, and study the coastal erosion patterns there. In particular, Area D was chosen, as East Coast Park covers quite a large area.

#### **1.6 Significance of research**

This research will be useful as with climate change, it is important to think in the long-term, and come up with more sustainable means of coastal management and protection measures, rather than come up with reactive short-term solutions. It is hence important to come up with more long-term proactive measures to counter rising sea levels in Singapore. This paper will hence be useful as it will aim to evaluate and analyse the effectiveness of current coastal management measures and come up with recommendations and solutions for a more sustainable future of coastal management.

#### **1.7 Limitations**

This research will be limited as it is only focusing on one (same stretch of) coast on Singapore, mainly the East Coast. Other coastal areas of Singapore face the same problem of rising sea levels, but the environment there may be different and require a different set of solutions.

Another limitation would be that the research will only last 1 year, and will be unable to detect some long term trends that require research over the course of years, if not decades.

## **1.8 Methodology**

This research will involve the quantitative analysis and research of coastal erosion rates through visitation of sites over time. Coasts will be measured using a metre rule.

For the perceptions of Singaporeans with regards to coast, a short questionnaire survey will be conducted to rank the various factors.

## 2 Literature review

### 2.1 The Bruun rule

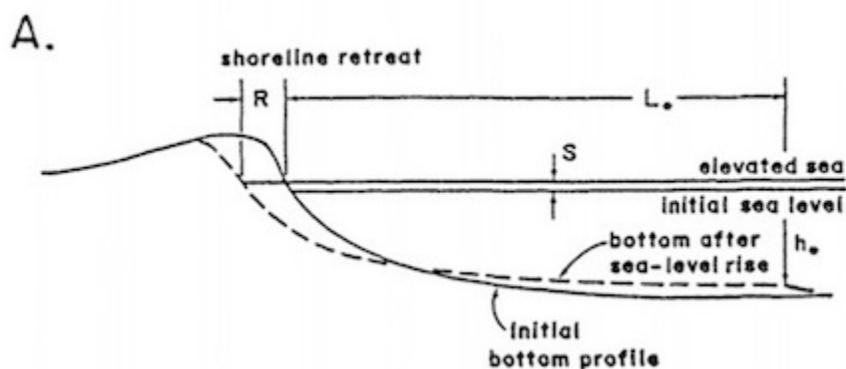


Fig 1A Bruun rule

The Bruun Rule is a formula for estimating the magnitude of the retreat of the shoreline of a sandy shore in response to changes in sea level. The Bruun Rule was the first to show a relationship between sea level rise and shoreline recession. The rule is a simple, two dimensional mass conversion, and remains in common use to estimate shoreline recession in response to sea level rise. It can also be modelled with the equation below

$$R = \frac{SL}{H+B} = \frac{SL}{\tan\beta}$$

Fig 1B. Bruun rule

However, it has become a hot topic of debate and criticisms (Covered in the next section)

### 2.2 Impact of sea level rise on erosion

Many researchers have studied the impacts of sea level rise on coastal erosion, such as (Zhang K, 2011) and Leatherman et al (2011), Mentaschi et al (2018). There has been a general

consensus that sea level does actually drive and hasten the pace of coastal erosion. Not only does it pose an existential threat for low-lying nations such as the Maldives, it speeds up the process of coastal erosion making these countries even more vulnerable to coastal erosion.

### **2.2.1 Rising sea levels**

Many scientists consider climate change that is driven by global warming as the most serious environmental threat facing the world today (IPCC 2007). Rising sea levels pose an exceptionally dire and almost life threatening threat; given that 10% of the world's population (634 million people) lives in low-lying coastal regions within 10 m elevation of sea level (McGranahan et al. 2007). Rising sea levels is particularly dangerous for coastal areas because in addition to inundating coastal areas, it essentially makes areas more vulnerable to extreme astronomical tides, storm surges and tsunamis. As sea level rises, storms of a given magnitude reach higher elevations and produce more extensive areas of inundation. (Fitzgarld et al, 2008).

Bruun's rule is the most cited method for quantifying the relationship between rising sea levels and coastal erosion. This rule was developed to mainly describe the behaviour of sandy coasts that have no cliff or wave cut platforms (which is applicable for East Coast Park, a sandy beach) It assumes that wave patterns over decades remain steady and consequently the (average equilibrium) beach profile does not change, but does translate up with the sea-level. Hence, based on the equilibrium profile theory it establishes a relationship whereby the rate of coastal retreat and the sea levels are directly proportional to one another. We can hence conclude that the shore face profile maintains an equilibrium shape , and as sea level rises the increasing accommodation space forces this equilibrium profile landward and upward to preserve its shape relative to the new sea level. (Aagaard et al, 2014)

In fact, there has been much debate over whether rising sea levels is the leading cause of coastal erosion and inundation. While there are other anthropogenic factors and human activity that may have affected and accelerated coastal erosion, despite the possible influence of these other factors, rising sea levels may still have served as the major forcing agent in promoting long-term erosion of coasts worldwide (Leatherman et al. 2000). The Bruun rule was also a topic of debate and criticism, given that more complex models were available and it may have been an oversimplification of the various complex coastal processes that could affect the coast. Some researchers have claimed that it was “not applicable for locations where the beach profile was not at an equilibrium” (Roshanka et al, 2007) Despite all of this criticism, some researchers still argue that the Bruun rule is still relevant, if it is constantly reviewed and updated when necessary, and is still supported by various researchers, and sea-level rise has been generally quantitatively related to shoreline retreat by the Bruun Rule. (Rosen,1978)

### **2.2.2 Conclusion**

Climate change, global warming and rising sea levels have become incontrovertible in recent years, and there is a general consensus that this is going to have a profound effect on coastal regions. For the case of Singapore and specifically East Coast Park, there are gaps in research as little is still known on the processes and dynamics, as well as factors such as rising sea levels affecting and reshaping this coastline and causing it to erode. (Deltares, 2013).

In addition, the understanding of how climate change and sea-level rise is quite underdeveloped and not well understood at this point of time. This is because the problem is that the type of model often used to bridge this gap (such as the Bruun rule) which is based on extrapolation of historic behaviour, is not really necessarily appropriate for such a relatively new phenomenon like climate change.

## **2.3 Impact of weather events on erosion**

Many researchers agree that extreme weather events such as storms and hurricanes have quite a devastating impact on coasts. These storms are able to bring along massive destructive waves, carrying away sediments from coasts and eventually causing shoreline retreat and coastal erosion. This is becoming especially more pronounced with more violent storms being fuelled by warming sea waters driven by global warming. Given that the form of a shoreline depends strongly on the climate of wave conditions it is exposed to, and larger waves are better able to erode both beach and land, this comes to show the devastating impacts of storms on coastal areas. (Coastal Wiki,2020)

Global climate change is expected to affect temperature and precipitation patterns, oceanic and atmospheric circulation, rate of rising sea level, and the frequency, intensity, timing, and distribution of hurricanes and tropical storms. (Michener et al, 1997)

### **2.3.1 Thunderstorms and Sumatra squalls**

One of the biggest reasons for coastal erosion is due to storms. Singapore, being located near the equator, experiences violent storms with high lightning activity quite frequently, due to strong daytime heating of land areas resulting in conventional rainfall. Thunderstorms have long been recognized as agents of geomorphic change to coasts, (Cahoon, 2006). Many researchers such as Reguero et al. (2019) or Nori et al. (2009) have found "long-term correlations and statistical dependency with sea surface temperatures, globally and by ocean sub-basins, particularly between the tropical Atlantic temperatures" There are clear regional dependence of annual average and extreme value from present to future climate. and that "There are clear

dependence of annual average sea temperature and extreme wave values from present to future climate."

The fact that storms affect coasts is an undisputed fact, and most researchers can agree that it affects coastal erosion. Many researchers have backed this, such as (Cornell et al, 2018), saying "The result, after a storm has passed, is a very different shoreline than before. The energy of water is awesome in its ability to move sediment from one place and deposit in another. This is often in conflict with the human desire to stabilize and prevent shorelines from moving. But storms and the shoreline naturally interact in a dynamic way." Storms have hence become oftentimes challenging to manage, with devastating impacts of storm surges that sometimes coincide with high astronomical tides causing inundated coastal areas. Similar to thunderstorms, Sumatra squalls are one of the main forms of precipitation that Singapore receives. Sumatra Squalls are common weather phenomena which have a very large impact affecting 85 million people throughout equatorial South East Asia. (Lo,2016) It is usually characterized by strong winds at the storm front, with a line of storms that develop in Sumatra and affect Singapore in the pre-dawn and morning hours. During the S.W. monsoon, strong winds resulting from the aforementioned. Some researchers have found out that Sumatra squalls can generate sea waves of approximately 1 m in height in open waters. At the coast however, breaker heights are generally found to be less than 0.2 m, because of refraction and dissipation by shallow waters, islands and coral reefs (Chia et al., 1988). During studies performed by Chew and Wei (1980) for the reclamations of Marina South and Marina East, maximum wave heights of 1.14 m were recorded, with Tz of 3 seconds. Again, there is a gap in research on exactly how storms that arise from strong daytime heating of land interact with the coasts in Singapore, given that it sometimes can be intense, coupled with strong winds and intense rainfall. Research on the impacts of Sumatra squalls are even more scarce, and its impacts on the coast are not very well studied.

## **2.4 Importance of coasts**

A number of researches have been conducted by researchers such as (Martínez, 2007, Pendleton, 2008) on the value of importance of coasts to people living near them. Its uses were very diverse, from tourism, to leisure and recreation, and agriculture fishing. This hence proves the point that it is really important to protect them, given its significance to many people's daily lives.

It is important to understand the perceptions that people have on coasts in order to understand the value of them in a given country. Many researchers found out that results on the value of coasts were vastly different from country to country. These results highlight the role that cultural and climatic settings play in influencing attitudes to beach use, and suggest that efforts should be made to maintain the diversity of beaches, providing a range of types from the amenity beach with a wide range of facilities to the less intensively used wilderness type. (MacLeod, 2007). In any given country, there will be a culture that is unique to them. The same applies for the value of coasts in a country, as the societal norms and culture would quite directly impact why people visit coasts for. In agricultural economies, coasts would be a source of income for many coastal communities. In tropical island countries like the Maldives or Bora Bora, coasts would also be a source of income, but in that their beautiful coasts attract tourists. In many developed countries, coasts may serve as a form of retreat rather than a source of income. As a result, the value of coasts would be one that is unique to Singapore.

## **Chapter 3: Methodology**

### **3.1 Physical Survey of beaches**

Over the course of 6 months (January 2021-June 2021), visits to East Coast Park were conducted. A total of 8 visits were conducted, each with different weather conditions in order to draw a conclusion from the results observed. Primary data was collected via the measurement of the length of the breadth of the beach in order to observe how the various weather phenomena would affect the results.

For the collection of primary data, photographs would be taken at the same piece of coastline in order to make visual analysis, observations and comparisons. For the measurements of the breadth of the beach, a metre rule would be used to measure the length of the breadth of the beach. Although long term measurements and statistics are unavailable for this particular study, some conclusions have been made based on the available data collected.

### **3.2 Survey questionnaire**

A survey questionnaire was conducted in order to gauge opinions and the attitudes of Singaporeans so as to determine the value of coasts in Singapore. A list of the questions can be found in *Appendix A*. The platform used to conduct the survey was Google forms, as the current circumstances of the pandemic posed a challenge to conduct on-site surveys. A mix of open ended and checklist questions were utilised to come up with the results. The open ended questions required the respondents to elaborate on why they preferred beaches over say, a typical park, and the various factors that made beaches more attractive to them. Checklist questions (Yes/No) were utilised in order to find out the percentage of respondents that have been to beaches in Singapore and East Coast Park before.

## 4 Discussion and Analysis

### 4.1 Summary of visitation of coasts

*\*In chronological order*

<b>Date</b>	<b>Conditions</b>	<b>Length of unprotected coast/m</b>	<b>Length of protected coast/m</b>
24 February 2021	Low tide, calm winds, clear skies	20.3	21.5
28 February 2021	High tide, strong winds (NE monsoon surge <sup>1</sup> ), no rain	4.9	4.8
14 March 2021	High tide, fair and warm	5.4	6.1
3 April 2021	Low tide, a day after intense storm, cloudy	20.1	20.9
26 May 2021	Sunny and breezy, High tide	5.1	5.2
13 June 2021	High tide, After intense storm	4.4	4.6
29 June 2021	High tide, after Intense morning Sumatra squalls	4.2	4.6

Fig 2 Summary of findings

A total of 7 visitations had been made to East Coast Park Over 6 months, in varying conditions. The results obtained are shown in Fig. 2 above. The results will be discussed in detail in the upcoming sections of this paper.

<sup>1</sup> During the northern hemisphere winter (December – March), high pressure systems frequently develop over continental northern Asia, and bring dry conditions and cold subsiding air over the northern Asian landmass. At times, a sudden increase in wind speed causes the cold subsiding air to surge southwards into the South China Sea towards low pressure systems in the southern Hemisphere. This sudden surge of cold air is referred to as a Northeast Monsoon surge.

#### 4.1.1.1 Tides

High tide mean/m (Protected)	Low tide mean/m (Protected)	High tide mean/m (Unprotected)	Low tide mean/m (Unprotected)
21.3	20.2	4.8	5.1

**Fig 3 Tides**

After the 7 visits to the beach, some observations have been made about the tides. Only 2 out of 7 visits made were during the low tide however because the main focus of this study was for the high tide. The high and low tides differed by around 15 metres, which is quite a lot. One observation made was that sometimes during the high tides, there would not be much distance left between the coast and the sea, leaving the area susceptible to storm surges and waves crashing into the pavements.

The tide in the Singapore Strait results from a combination of tidal characters in both the South China Sea and the Bay of Bengal, a bay in the Indian Ocean. In the South China Sea, the tidal character is mixed and predominantly diurnal. In the Bay of Bengal the tidal character is predominantly semi-diurnal. In the Singapore Strait, then, a mixture of these tides invokes a complex regime with considerable tidal asymmetry, consisting of a predominantly semi-diurnal vertical tide and a predominantly diurnal horizontal tide.

#### 4.1.1.2 Coastal erosion in East Coast Park

As mentioned above, during the high tide there was not much distance between the coast and the sea. Various photos were taken along various points of East Coast Park that clearly depicted the erosion going on in East Coast Park.



Fig 4. (a),(b) Photographs taken at East Coast Park

There is clear evidence of coastal erosion at East Coast Park as shown in the photographs above. The photos that were taken above show two similar phenomena, where the soil in the coastline has eroded away. This may suggest that in the incidence of intense storms with high winds combined with high tides, it may have brought destructive waves to the coast hence eroding away some of the soil, revealing the roots of the trees. Other than the photographic evidence of the erosion going on in East Coast Park, the data collected in Figure 2 seems to suggest a decline in the breadth of the coast over the six months. While this is not conclusive evidence that this is as a result of coastal erosion, we can observe that for the unprotected coast and the protected coast, the breadth of the coast seems to be following a decreasing trend over the past 6-7 months.



Fig 5. Breadth of coast

We can deduce from this that Singapore is not safe against rising sea levels and that coastal erosion is indeed taking place. Rising sea levels may be playing a part for this phenomenon as the sea levels and water go further and further inland, and with more intense and dangerous storms bringing in larger storm surges.

#### 4.1.2.1 Effect of Monsoon on coast

For the earlier parts of this study, the Northeast monsoon affected Singapore from (November 2020 to March 2021). This would mean that there would be monsoon surges that may potentially pick up wind speeds, making the waves more destructive. The comparison can be seen below.

NE Monsoon surge/m	Calm conditions/m
4.9	5.8

Fig 6. Average breadth of coast, Monsoon comparison

There is an almost 1m difference in the breadth of the beach, between the presence of a monsoon surge and calmer, less windy conditions. One reason for this may be that the monsoon and the monsoon surges affect both the character of the wave climate and also the angle of incidence of the waves. During monsoon surges, more energetic and destructive waves will prevail, which will lead to a lot more rapid coastal erosion. One observation made was that the readings taken during the Northeast monsoon surge was higher than that of after the intense storms. This may suggest that the erosion that takes place during such events is not as dramatic and short-term compared to that of storms. One possible explanation for the slight difference may be that due to the winds, the angle of incidence of the waves approaching the beach change and cause different patterns of longshore drift along the coast.

The monsoon winds may also affect the level of the tides, by generating currents in the Singapore Straits, especially during the Southwest monsoon.

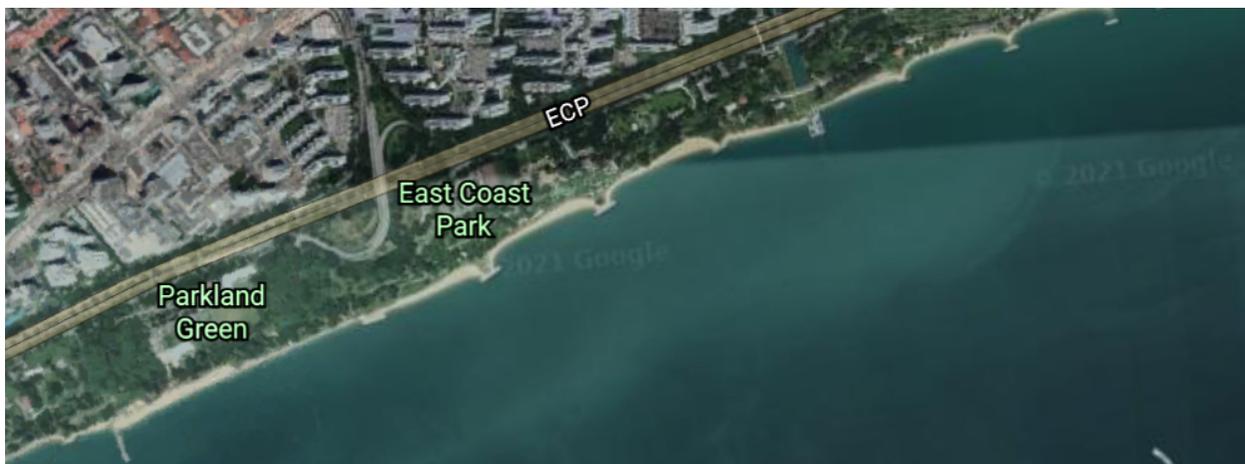
#### **4.1.2.2 Effect of storms and sumatra squalls on coast**

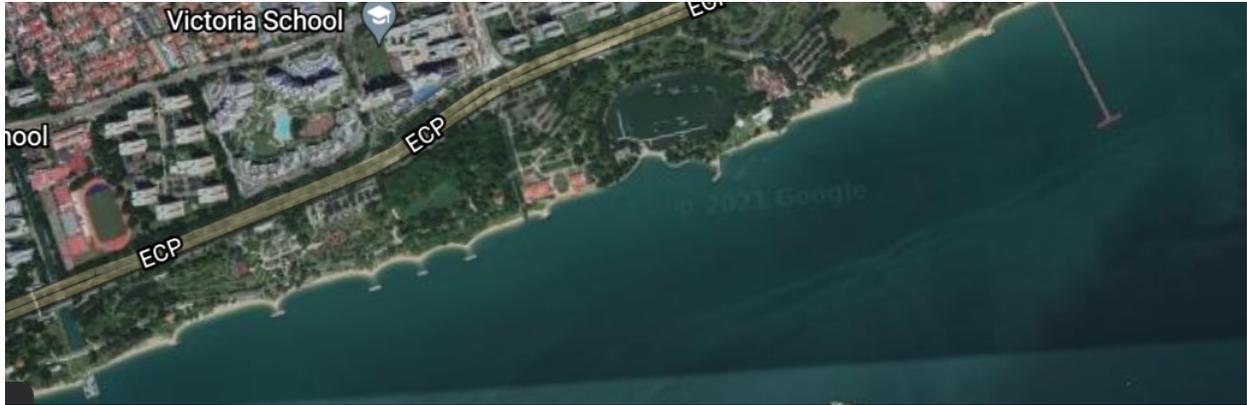
During the Southwest monsoon, Sumatra squalls tend to occur quite frequently. These squalls are lines of thunderstorms coming from Sumatra and the Strait of Malacca, that cause rapid increases in wind speeds and precipitation. Afternoon thunderstorms usually occur causing similar effects, but are usually caused by a convergence of winds as a result of strong daytime heating of landmass.

The results show that after these storms the breadth of the beaches show a temporary decrease. These may be because of the swell and the more energetic waves that increase the speed of sedimentation, as well as more destructive waves bringing away material from the beach.

#### 4.1.3 Effectiveness of protection strategies in East Coast Park

Based on the results from Figure 2, there is clear evidence that the protection measures have been effective in protecting the coast from erosion. The evidence is quite conclusive as the results have been relatively consistent for most of the time. This can be seen as a successful implementation of the headland control. The gabion breakwaters have allowed for the formation of bay-like structures along the coast. (Fig 7a-c). During the phases of the East Coast Reclamation initially a seawall was implemented, which led to erosion of the sand and undermining of the seawall, especially at the eastern tip. Hence, in order to prevent further erosion and create stable beaches, a new approach was adopted, originating from Silvester (1960), who described stabilization of sedimentary coastlines by means of hard structures. The idea was to implement a series of breakwaters along the coast, in order to improve shoreline stability and simultaneously alleviate the construction and maintenance costs the seawall brought along with it.





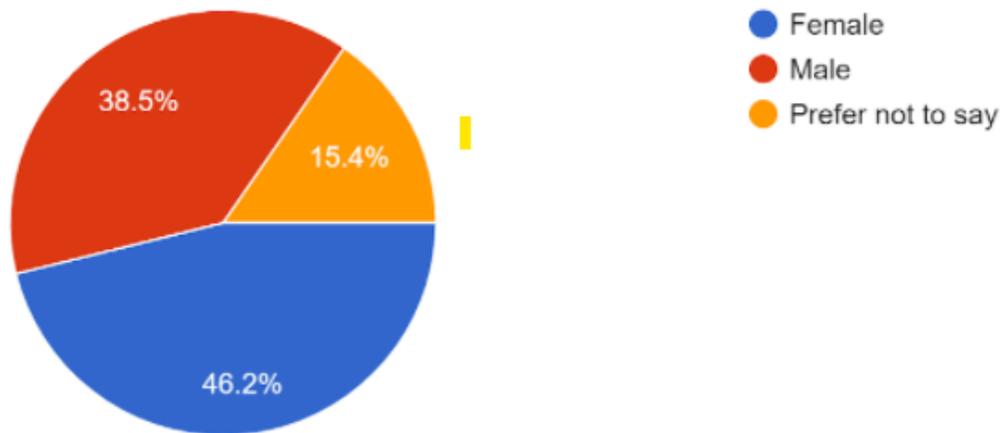
**Fig 7a, 7b, 7c** *Top: The Eastern section of East Coast Park, breakwaters/headlands 1-11 Middle: Central section of East Coast Park, breakwaters/headland 12-18*  
*Bottom: Eastern section of East Coast Park, breakwaters 19-25*

#### **4.1.4 Other comments**

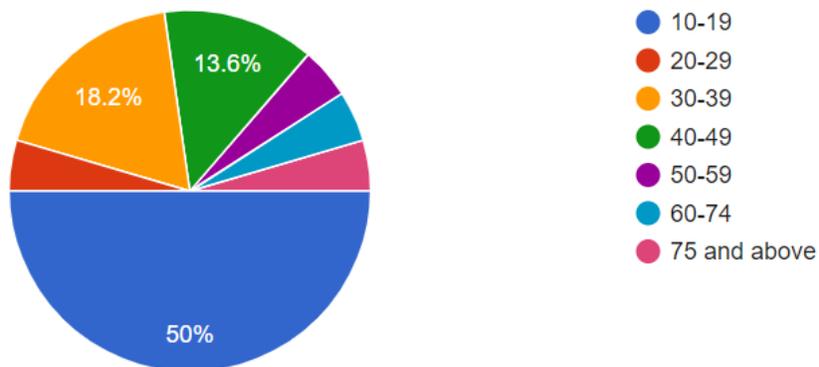
The study above has indeed shown some relatively clear relationships between the various weather phenomena and the rate of coastal erosion. However, we have to take into account that these results are not fully conclusive, given the short timespan of the research and it would be incorrect to simply state that these trends observed would be true all the time.

## 4.2 The Value of Coasts

A survey was conducted on 25 individuals on the value of coasts. There was a relatively equal representation of both genders and a decent variety of age groups. The questions asked in the questionnaire can be found in Appendix A.



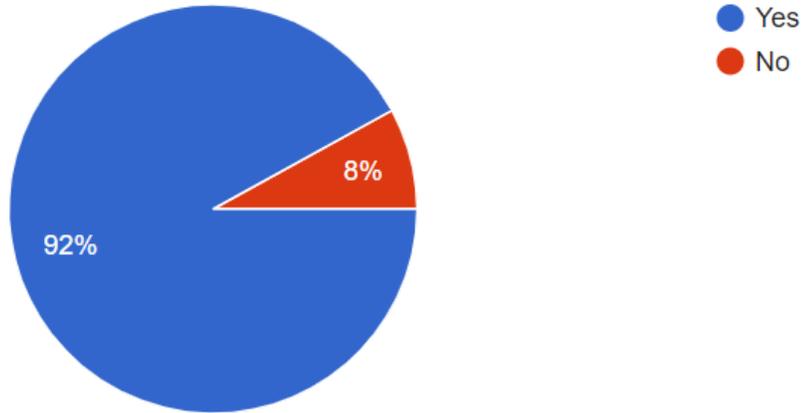
**Fig 8 Gender of respondents**



**Fig 9 Age of respondents**

Have you been to any beaches in Singapore?

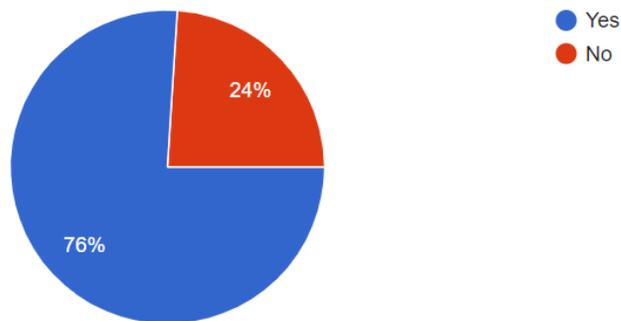
25 responses



**Fig 10 Question 1 Results**

Have you been to East Coast Park before?

25 responses



**Fig 11 Question 2 Results**

As seen in Figure 10 and Figure 11, most respondents have been to beaches in Singapore before (92%) This number is very high compared to the global average, which shows us how valuable our beaches are. In such a small country like Singapore, where recreational activities are limited as a result of the confined living space that we live in, it can be said that beaches

have a special place in many Singaporeans. East Coast Park might also be one of the most iconic beaches in Singapore, with 76% of respondents saying that they have been to East Coast Park before. This is despite the relatively difficult accessibility of the area given the lack of a MRT line and location making it difficult to go to without a car. The results are somewhat surprising as a result. During the 7 visits to East Coast Park, it was also observed that the park was always very crowded despite it being the pandemic period, testifying its popularity amongst Singaporeans.

The interview questions involved asking the respondents open ended questions on why they liked going to beaches and what set beaches apart from other parks. The various answers were categorised into categories.

<b>Reason</b>	<b>Number of respondents</b>
Leisure	8
Sports (Frisbee, Swimming, Cycling)	13
To enjoy the sea	7
To bond with family and friends	4
Other	1

**Fig. 12**

The most commonly cited reason was for exercise purposes, especially for that of cycling. It seems to be that cycling has become a very popular sport and leisure activity among Singaporeans, and many Singaporeans choose to go to East Coast Park and various other beaches in Singapore to cycle. This can be explained by the good infrastructure and cycling paths that are built along the beaches. Another commonly cited reason is for relaxation and leisure purposes (9 votes) and the calming effect of the sea (7 votes). This result is also not

surprising, as the sea has long been associated with natural beauty and calm. We all have a “blue mind” that is a mildly meditative state characterized by calm, peacefulness, unity, and a sense of general happiness and satisfaction with life in the moment. (Marine J, 2019)

In conclusion, it can be said that coasts and beaches are indeed a significant part of being a Singaporean, and are a part of life in Singapore.

## **5 Conclusion**

There have been many driving forces for the quickening pace of coastal erosion in East Coast Park. In this paper, driving forces such as the monsoon, sea level rise, sumatra squalls, thunderstorms and tides have been discussed. The answers to the research questions have been mostly touched upon. However, the coast is dynamic. East Coast Park is still a very young coast as it is on reclaimed land and whether it has reached equilibrium is impossible to tell unless we observe it for a very long period of time. Overall, the coast’s rate of erosion seems to be affected with seasonal variability, and also short term erosion as a result of storms such as Sumatra squalls and afternoon thunderstorms as a result of strong daytime heating of land.

For the future of the coast, it is important to continue getting up to date data on the rate of erosion and wave heights so as to monitor the trends in erosion and prepare for more measures if necessary. Coastal processes should be analysed in greater detail.

The coast is of great importance for Singapore. It has proven to be a lifestyle in Singapore, an integral part of living in Singapore. It is hence important to protect these coasts so that the future generations will also be able to enjoy them.

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## **Appendix**

Link for survey questionnaire

[https://docs.google.com/forms/d/e/1FAIpQLSd-PTXw6qlg\\_SKninb1cOhnmVsSy1PQZU2xGq7PBV7r21IDtg/viewform?usp=sf\\_link](https://docs.google.com/forms/d/e/1FAIpQLSd-PTXw6qlg_SKninb1cOhnmVsSy1PQZU2xGq7PBV7r21IDtg/viewform?usp=sf_link)