Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(4): 263 – 282 (2025)
www.ejabf.journals.ekb.eg

Whale Sharks (*Rhincodon typus*) in Botubarani Ecotourism Development Zone: Presence, Oceanographic, and Geomorphic Bathymetry Characters

Nuralim Pasisingi[1*], Abdul Hafidz Olii[1], Faizal Kasim[2]

[1]Aquatic Resources Management Study Programme, Faculty of Marine and Fisheries Technology, Universitas Negeri Gorontalo, 96128, Gorontalo, Indonesia
[2]Marine Science Study Programme, Faculty of Marine and Fisheries Technology, Universitas Negeri Gorontalo, 96128, Gorontalo, Indonesia
[*]**Corresponding Author: nuralim@ung.ac.id**

ARTICLE INFO

Article History:
Received: March 23, 2025
Accepted: June 30, 2025
Online: July 5, 2025

Keywords:
3D benthic habitat,
Gorontalo,
Marine conservation,
Principal component analysis,
Tomini Bay

ABSTRACT

Unlike whale shark appearances in other locations worldwide, which typically occur far from land, their presence near the mainland in Botubarani is a unique phenomenon. Therefore, collecting and analyzing the factors that determine the presence of whale sharks in Botubarani waters is essential. This research identified patterns in whale shark appearances within the Ecotourism Development Zone and examined their relationship with oceanographic parameters and geomorphic-bathymetric characteristics in Botubarani. Appearance data from 2016 to 2021 were collected from published scientific articles and further validated through structured interviews with the local community. Oceanographic data were analyzed to understand the local whale shark habitat from a 3D geomorphic bathymetric perspective, and to determine the relationship between sea surface temperature (SST) and surface chlorophyll-a (Chl-a) concentrations with whale shark appearances. A steeper deep cleft is strongly associated with whale shark presence near the coastline, where unique seafloor features and sheltered reef and coral/algae habitats are found. The analysis showed that Chl-a concentration is a stronger determinant of whale shark appearances than SST. This research highlights the importance of predicting whale shark occurrences in Botubarani waters to support conservation strategies and offers insights into the environmental factors influencing their presence, aiding efforts to protect this endangered species.

INTRODUCTION

The habitat range of the whale shark (*Rhincodon typus*) includes shallow coastal and deep waters in warm tropical and subtropical areas, except in the Mediterranean Sea. The whale shark (*R. typus*) is a pelagic species commonly found offshore and close to land, entering lagoons and coral atolls and near the mouths of estuaries and rivers to forage for food **(Colman, 2007)**. Tracking satellites have detected whale sharks migrating long distances across international waters **(Block *et al*., 2011)**. During these migrations,

whale sharks encounter various ecological challenges caused by both natural and anthropogenic factors. Many marine species undertake transoceanic migrations between hemispheres to optimize growth, foraging, or breeding opportunities across different geographic regions **(Luschi, 2013; Guzman *et al.*, 2018)**. Due to their ecological importance and vulnerability, whale sharks receive special attention globally, particularly regarding their long-term sustainability.

Since 2002, whale sharks have been listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora **(CITES, 2023)**. In 2016, the International Union for Conservation of Nature (IUCN) classified the whale shark as an endangered species **(Pierce & Norman, 2026)**. In Indonesia, whale sharks have been fully protected since 2013 under the Decree of the Minister of Maritime Affairs and Fisheries Number 18 of 2013, which granted full protection status to *Rhincodon typus*.

Whale sharks (*Rhincodon typus*), the largest known shark species, are widely distributed in oceans around the world **(Sequeira *et al.*, 2014)**. In Indonesia, they are observed in nearly all marine regions. However, their appearance is seasonal, with the exception of the Kwatisore Region in Cenderawasih Bay, Papua, which overlaps with the Cenderawasih Bay National Park **(Maruanaya *et al.*, 2022)**. In Gorontalo waters, as well as other Indonesian territorial waters—including Sabang, Padang, Ujung Kulon, Kepulauan Seribu, Probolinggo, Kenjeran (East Java), Derawan (East Kalimantan), Bali, Nusa Tenggara, Central Sulawesi, Spermonde (South Sulawesi), Maluku, and Papua—their presence is limited to specific periods.

To date, the reasons for the unpredictable appearance of whale sharks in the wild, particularly in Botubarani waters, remain unclear. This unpredictability poses significant challenges for local tourism managers who rely on their presence for ecotourism.

Understanding the factors that determine the presence of whale sharks in Botubarani is essential to support the development of a sustainable and efficient ecotourism program. Observations from 2016 to 2017 suggested a strong correlation between whale shark appearances and food waste from a nearby shrimp processing factory **(Sino *et al*., 2016; Mile *et al.*, 2017)**. However, more recent findings by **Rosalina *et al.* (2021)** revealed that whale sharks continued to appear in the area even after the factory ceased operations. This indicates that factors beyond food availability may significantly influence whale shark presence in Botubarani.

In this study, we hypothesize that oceanographic and geomorphological characteristics of the Botubarani waters play a significant role in the appearance of whale sharks. Therefore, initial research should adopt a single-factor approach and then expand to a multi-factor analysis to more clearly identify the determinants of whale shark presence—particularly in the Ecotourism Development Zone of Botubarani waters.

Previous scientific literature has shown that whale sharks often migrate to areas with high food availability, commonly indicated by elevated chlorophyll-a concentrations

in the water. This research contributes new insights by identifying appearance patterns of whale sharks specifically within the Ecotourism Development Zone of Botubarani. Accordingly, the study aimed to investigate the spatial and temporal patterns of whale shark appearance and their relationship with oceanographic parameters and geomorphic-bathymetric characteristics in Botubarani waters.

MATERIALS AND METHODS

Several studies have indicated a relationship between whale shark appearances and oceanographic factors such as sea surface temperature (SST) and surface chlorophyll-a concentration (Chl-a). For example, in Teluk Cenderawasih National Park (TCNP), the frequency of whale shark sightings is closely associated with the presence of fisherman lift nets and anchovy populations, both of which are influenced by oceanographic factors such as Chl-a and SST. These parameters significantly affect anchovy catch rates and, consequently, whale shark sightings, although not consistently across all seasons **(Ihsan *et al.*, 2018)**.

In addition, in Cenderawasih Bay**, Ranintyari *et al.* (2018)** found that sea surface currents were better predictors of whale shark appearances than SST or Chl-a concentration. In a separate study, **Kumari and Raman (2010)** analyzed satellite data from 1998 to 2000 to examine the relationship between whale shark landings, phytoplankton concentration, and SST on the continental shelf and offshore areas of Gujarat. They concluded that combining ocean color and SST imagery is an effective tool for identifying potential aggregation areas.

In Ningaloo Reef, Western Australia, **Marcus *et al.* (2016)** used signature fatty acid analysis to study whale shark diets and foraging ranges, revealing intraspecific diet variability that suggests different foraging strategies among individuals. More recently, **Copping *et al.* (2018)** identified bathymetric features associated with coastal whale shark aggregations, reporting that aggregation sites were generally closer to mesopelagic zones, shallower, and had steeper slopes compared to non-aggregation sites. They also found that benthic complexity was significantly lower at aggregation sites.

Although the relationships between whale shark appearances and oceanographic variables like Chl-a, SST, and bathymetry are not consistent across all seasons and regions, the literature suggests a clear correlation. These studies emphasize the importance of local oceanographic conditions in supporting temporary whale shark habitats near coastal areas in Indonesia.

The aim of our current research was to identify these influencing oceanographic factors in Botubarani waters using geospatial data and to analyze their daily, monthly, and seasonal (monsoonal) patterns. This analysis supports the effective management of temporary whale shark habitats and contributes to sustainable conservation efforts, particularly in the support of their role as an ecotourism attraction in the Botubarani region.

The whale shark appearance data used in this research are limited to sightings within the Ecotourism Development Zone in Botubarani, as the presence of this megafauna is almost exclusively recorded in this area. To reduce potential bias from data collected outside this zone, we conducted structured interviews with long-term local residents to confirm the consistency and accuracy of the occurrence patterns gathered from various sources.

Data collection

Whale shark appearance

Monitoring the whale shark (*Rhincodon typus*) appearance in Gorontalo has been conducted by the Makassar Coastal and Marine Resource Management Center (BPSPL) since 2016 using two acoustic receivers, installed in the waters of Leato Selatan and Botubarani, respectively **(Handoko *et al.*, 2017)**. However, due to the limited data available from Leato Selatan, this study focused exclusively on Botubarani waters, particularly within the Ecotourism Development Zone.

In this research, data on whale shark appearances in Botubarani were obtained through the collection of secondary sources, including published scientific articles and research reports accessed via Google Scholar, Semantic Scholar, and the Google search engine. We compiled daily and monthly records of *R. typus* sightings in Botubarani from 2016 to 2021. To ensure data relevance and accuracy, we excluded any record of sightings that occurred outside the designated Ecotourism Development Zone.

In addition to secondary data collection, direct field surveys and structured interviews with local residents were conducted to provide supplementary information and to validate the findings derived from the secondary sources.

Oceanography parameters and 3D bathymetry habitat geomorphic model

The primary data used in this study include sea surface temperature (SST), sea surface chlorophyll-a (Chl-a) concentration, and the bathymetric profile of Botubarani waters.

To collect SST and Chl-a data, we utilized MODIS Aqua Level 3 gridded datasets with a spatial resolution of approximately 5km (4,616m), which are widely employed for biological and hydrological observations in coastal environments **(JPL/OBPG/RSMAS, 2020; NASA OB.DAAC, 2023)**. These datasets, which are available as daily records, were processed using a mean function to derive average monthly SST and Chl-a values for the period 2016 to 2022. Data extraction and filtering were conducted using the Google Earth Engine platform, which provided efficient access to cloud-hosted datasets. This method was chosen due to the unavailability of continuous, time-series data across the observation period.

To model the bathymetric profile of the study area, we employed 1:50,000-scale isobath contour shapefiles and DEMNAS (Digital Elevation Model Nasional) datasets.

These resources were obtained from the Geospatial Information Management and Dissemination Center of the Geospatial Information Agency (Ina Geoportal, 2023). The high spatial resolution of the isobath data enabled accurate construction of a 3D geospatial model to better understand the local habitat features associated with whale shark appearances.

Additionally, geomorphological observations of the underwater landscape, specifically the distribution of coral reefs, were conducted using data from the Allen Coral Atlas (ACA) – *Geomorphic Zonation and Benthic Habitat v2.0* dataset **(Allen Coral Atlas, 2020; Kennedy *et al.*, 2021)**. Bathymetric and geomorphic modeling was carried out using ArcGIS and ArcScene software. The workflow to construct the 3D bathymetric-geomorphic model involved several steps:

1. resampling the DEMNAS data,
2. converting raster data into elevation points, and
3. interpolating these points into a Digital Surface Model (DSM) using the "Topo to Raster" technique.

The boundaries used for screening oceanographic parameters and constructing the bathymetric-geomorphological model were defined based on the spatial extent of the study area, as shown in Fig. (1). A summary of all data types utilized in this study is provided in Table (1).

Table 1. Scope and references of research data

Scope	Sources
Monsoon and monthly appearance of whale shark	**Sino *et al*. (2016)**; **Handoko *et al*. (2017, 2019)**; **Mile *et al*. (2017)**; **Rosalina *et al*. (2021)**; **Rombe *et al*. (2021, 2022)**; **Baderan *et al*. (2023)**
The daily appearance of whale shark	
Sea surface temperature (SST) and surface chlorophyll-*a* (Chl-*a*) concentration	Level 3 band products Google Earth engine data catalog provided by **NASA OB.DAAC (2023)**
3D Bathymetric profile	Isobath contour and National Digital Elevation Model (DEMNAS) scale 1:50k, from **Indonesian Geospatial Board (2023)**,
Benthic Geomorphic zonation habitat	The raster map of classification of geomorphic zonation and dominant benthic composition, resolution 5 m by **Allen Coral Atlas (2020)**; **Kennedy *et al*. (2021)**
Distance whale shark from the shoreline to the area appearance	Interviews with people of boats servicing the community for whale shark attraction and field observation from January to April 2023

Data analysis

The analysis of geomorphological habitat and bathymetry in the whale shark appearance area (Fig. 1) was conducted descriptively, based on a three-dimensional (3D) Digital Surface Model (DSM) of geomorphic bathymetry generated through modeling and data overlay. Whale shark appearances were visualized in graphical form to illustrate spatial patterns.

To examine the relationships between whale shark appearance patterns and oceanographic variables, including sea surface temperature (SST) and chlorophyll-a (Chl-a) concentration, statistical analyses were performed. Linear Regression and Principal Component Analysis (PCA) were conducted using Minitab version 14.12 to identify correlations and principal factors influencing whale shark occurrences in the study area.

RESULTS

Approach overview

The whale shark tourism attraction in Gorontalo is considered one of the most accessible and exciting in Indonesia, as the sightings occur less than 100 meters from the coastline. Currently, two designated areas related to whale shark management in Botubarani waters have been reserved by the Provincial Government of Gorontalo and are available through public online platforms.

The first is the Botubarani Coastal Waters Protection Area for Whale Sharks, which is documented on the Gorontalo Geopark website: https://geopark.gorontaloprov.go.id/sites/daftar-biosite/botubarani-whale-shark-site/.

The second is the Sulawesi Conservation Area for Whale Shark Ecotourism, which is included as part of an interactive map of conservation areas within the Makassar BPSPL working region, accessible through the ArcGIS application **(Esri Indonesia, 2023)**.

Both maps serve as key references for defining the management zones and research locus of this study and are presented in Fig. (1).

.

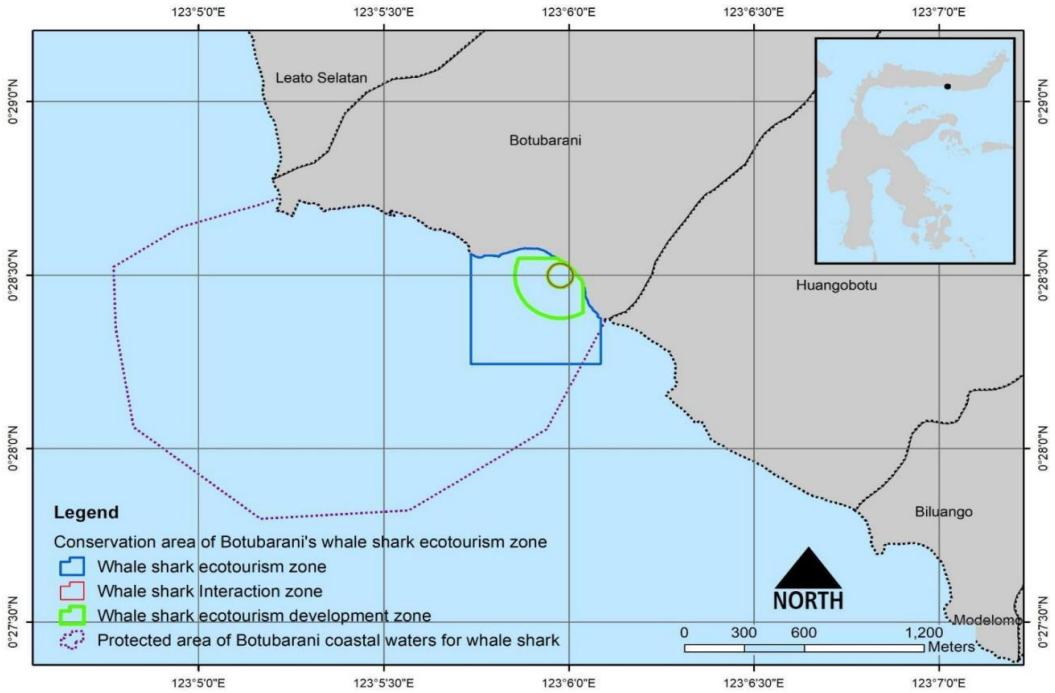


Fig. 1. The area of interest of research consists of the coastal waters of whale shark tourism protected areas in Botubarani, Gorontalo, Sulawesi **(Geopark Gorontalo, 2023)** and the conservation of Botubarani's whale shark ecotourism area, which is consisted of the interaction zone, development zone, and ecotourism zone **(Esri Indonesia, 2023)**

Whale shark appearance pattern in Gorontalo

The Tourism Awareness Group and *Deheto Tinelo*, under the coordination of BPSPL Makassar, conduct daily underwater observations to monitor whale shark appearances and capture identification photographs of individual sharks. The collected data are then compiled and reported as a seasonal calendar, which is displayed on an infographic board at the tourist site.

Fluctuations in the appearance of individual whale sharks in Botubarani (Fig. 2) indicate a noticeable trend: from 2019 to 2021, whale sharks appeared almost every month. In contrast, during the previous three years (2016–2018), sightings were far more sporadic and did not occur consistently each month. This emerging pattern supports a hypothesis that whale sharks may be shifting their migratory behavior toward a more sedentary lifestyle in the Botubarani area.

In other words, Botubarani—part of the broader Tomini Bay ecosystem—may serve as a potential nursery ground, with the same individuals appearing repeatedly. However, this hypothesis requires further scientific validation due to the complexity of factors influencing whale shark behavior, including internal biological processes and external aquatic environmental dynamics.

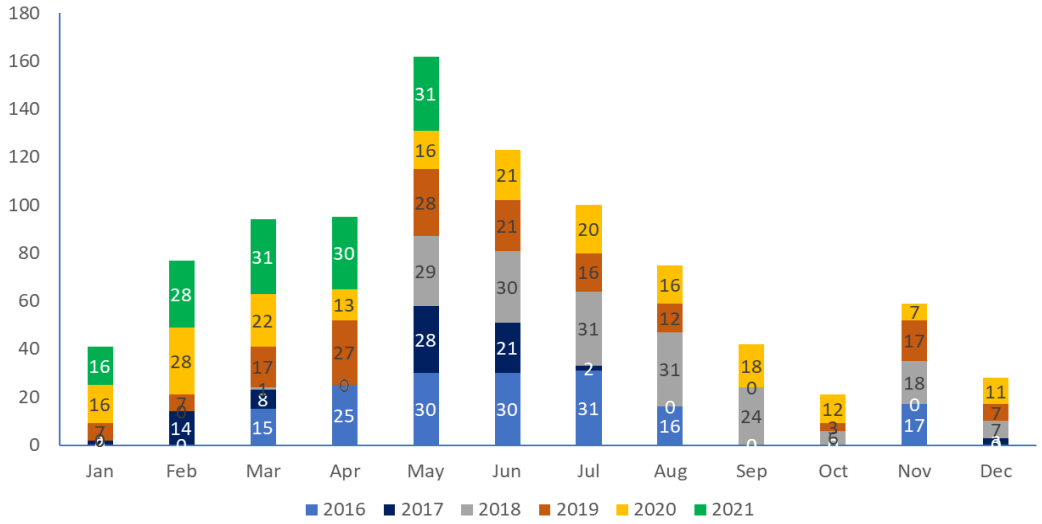


Fig. 2. Monthly appearance of Whale Shark (individuals) in Botubarani Ecotourism Development Zone from March 2016 to September 2019 (Source: BPSPL Makassar *in* **Handoko *et al*., 2017, 2019**), October 2019 to March 2020 (Source: **Rosalina *et al*., 2021**), April 2020 to July 2020 (Source: BPSPL Makassar *in* **Handoko *et al*., 2017, 2019**), August 2020 to May 2021 (Source: **Rombe *et al*., 2022**).

Geomorphic bathymetry of the whale shark appearance habitat in Botubarani coastal waters

The appearance of the 2D and 3D geomorphological models of the bathymetry of the habitat for whale sharks in Botubarani waters is presented in Fig. (3). The bottom slope profile of the waters and the depth of this area are shown in Fig. (4). The bottom area of the Botubarani coastal waters and the surrounding area are generally composed of sheltered reef geomorphological formations. The slope stretches from the bottom of the coastal waters of South Leato in the west to the coastal waters of Huangobatu in the east. This geomorphological zonation formation is found up to a depth of 35m. This type of geomorphological formation is an essential habitat for coral/algae, which is dominant at the bottom of the waters of Botubarani and Huangobotu, as well as rock mixed with a small amount of seagrass at the bottom of the coastal waters of South Leato. Based on the appearance of the 2D model, which is detailed through the formation of the 3D model of the coastal seabed of Botubarani and the surrounding area in Figs. (3, 4), it is known that, in general, the bottom shape of the coastal waters of Botubarani and its surroundings which are part of the south coast of Gorontalo has a very narrow continental shelf profile. The continental shelf, which is generally characterized as less than 200m deep, is only ~600m from the Botubarani coastline. The seabed slope profile is less than 75m from the shoreline and is almost 20 degrees. The in-front seabed slope is varied, with a pattern of slope values ranging from 1.5 to 12 degrees at a distance of ~1,300 m from the coastline (Fig. 4). The uniqueness of the bottom profile of the waters, which is the habitat for the emergence of whale sharks on Botubarani beach, is the presence of a narrow gap feature

right in the whale shark ecotourism zone, which stretches diagonally to the front end of the RZW3P protected area. The element of a narrow bottom gap of the Botubarani waters, which is also found at the bottom of the South Leato waters, has a width of ~ 150 m at the bottom to ~ 300m near the surface and a depth of between 60m (near the shoreline) to 400m which is only 230m from the coastline (Fig. 4).

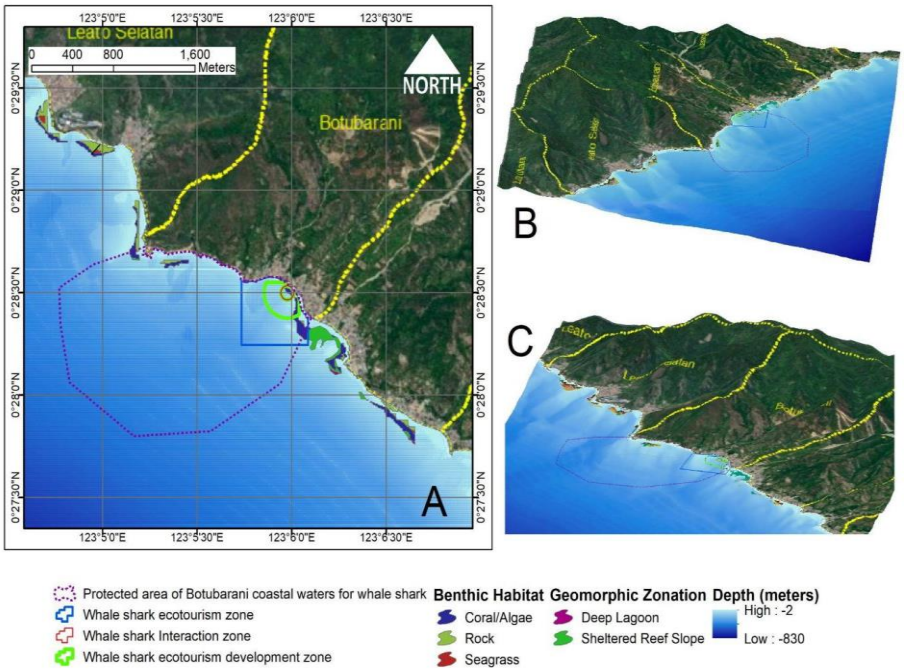


Fig. 3. 2D model (A) and 3D geomorphic bathymetry model with view direction from southwest (B) and southeast (C) of the habitat profile whale shark appearance in Borutabarani coastal waters

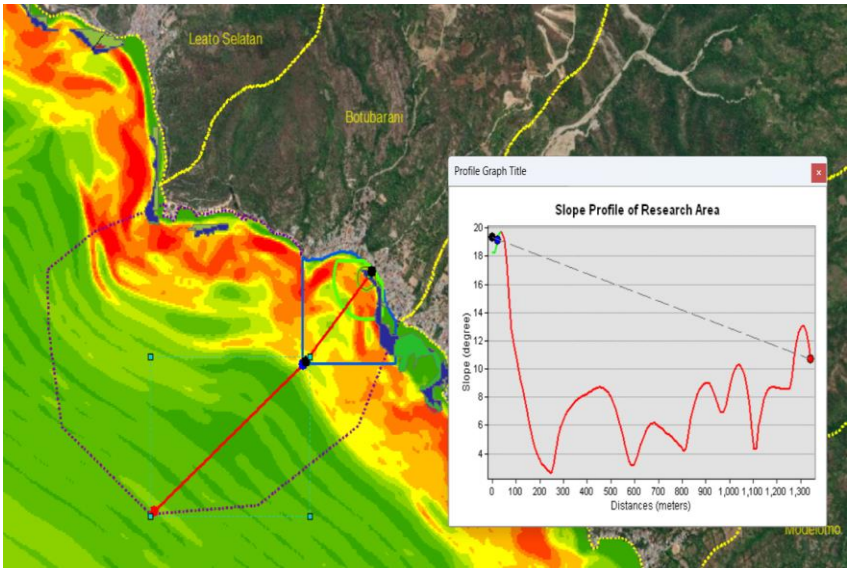


Fig. 4. Bathymetry profiles as whale shark habitat in Botubarani waters

SST and Chl-a in Botubarani waters as the habitat of whale shark

Studies related to observing the aggregation process of whale sharks in Indonesia on oceanographic parameters, such as those focused in this paper, will provide insight into how innovative conservation efforts can be carried out effectively toward the species *R. typus*. Although it is not specific as to what extent the effect is, environmental factors undoubtedly affect the behavior and migration of whale sharks. SST fluctuations in Botubarani ranged from 28.55– 31.43°C (Fig. 5). Its Chl-*a* surface concentration of Botubarani ranges from 0.12 to 2.24mg·m^{-3} (Fig. 6). Even though in September 2021, it appears that Chl-*a* reached 2.24mg·m^{-3}, generally, the values for these two oceanographic parameters are still within normal conditions. SST fluctuation of Botubarani only occurs ±2.88°C.

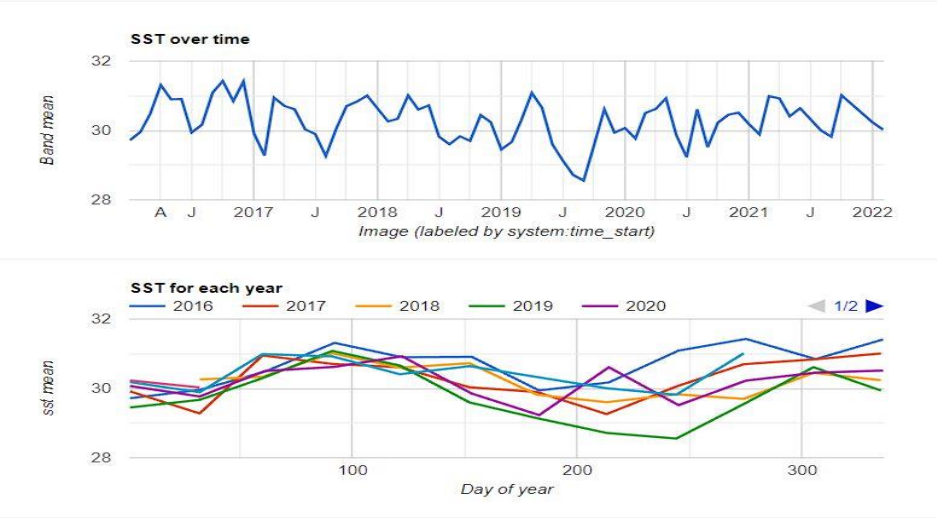


Fig. 5. Sea surface temperature (SST) of Botubarani waters during period of 2017 to 2022

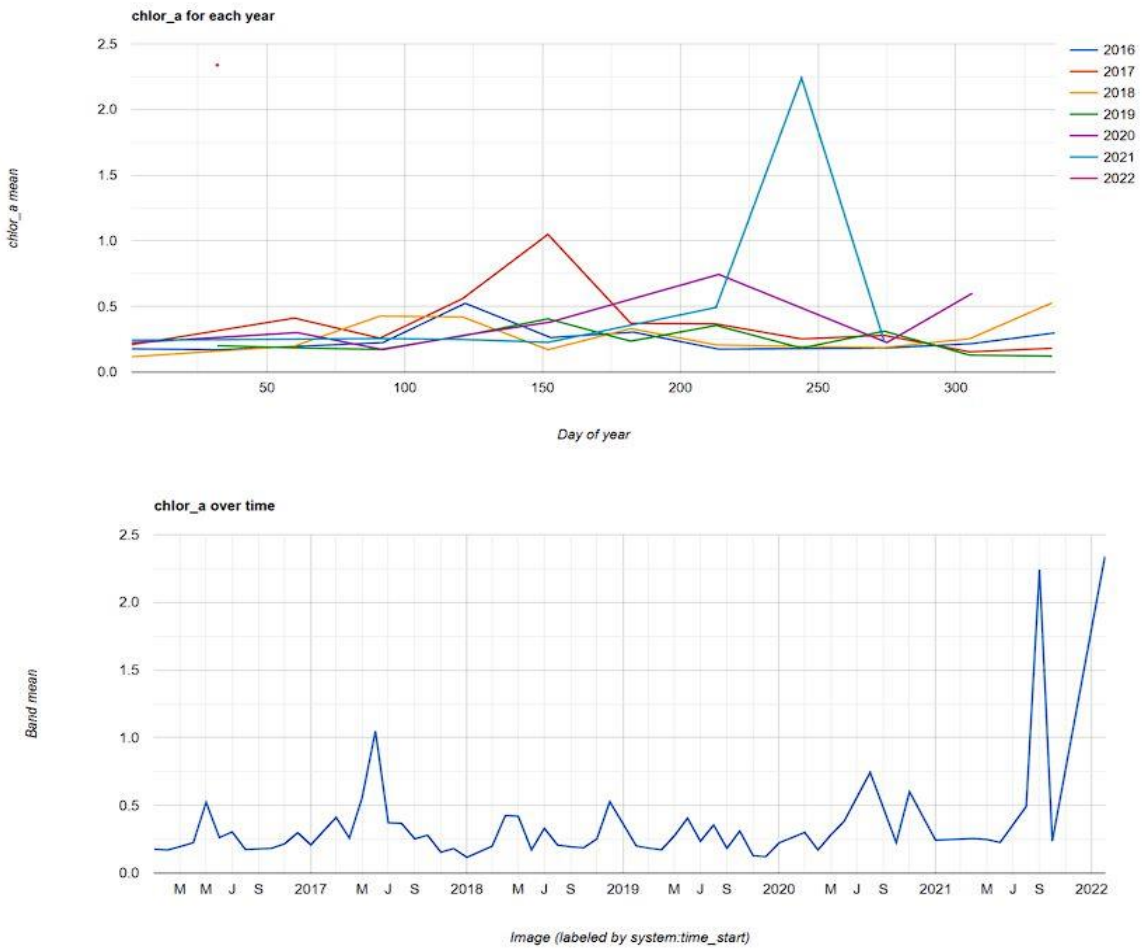
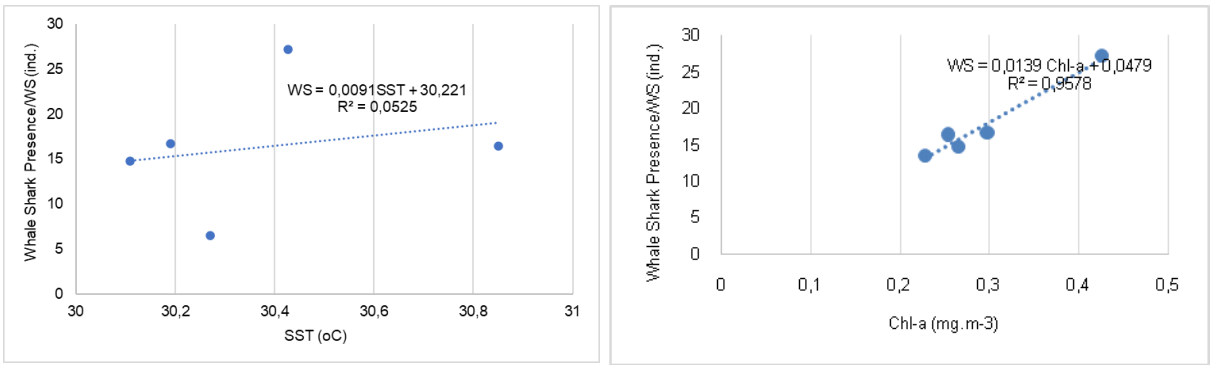


Fig. 6. Surface chlorophyll-*a* (Chl-*a*) concentration in Botubarani waters from 2017 to 2022

Along with temperature, the surface Chl-*a* concentration is an oceanographic factor that may be associated with the appearance of whale sharks in a particular area. The current study reveals that Chl-*a* is stronger in determining the emergence of whale sharks (WH Presence) than the SST parameter. The linear relationship of the presence to Chl-*a* has a high coefficient of determination (95.78%) compared to SST (5.25%) (Fig. 7). The results of this analysis are also strengthened by PCA results which exhibit that the Chl-*a* variable tends to characterize whale shark presence compared to the SST variable (Fig. 8). The Eigen analysis of the Correlation Matrix of the three variables shows a value of more than 0.5 for the First Principal Component (PC1), namely -0.602, -0.537, and -0.591, respectively for WH Presence, SST, and Chl-*a*. Whereas for the Second Principal Component (PC2), the WH Presence and Chl-*a* variables showed a positive correlation with values of 0.310 and 0.447, respectively. The SST variable for PC2 offers a high negative correlation value of -0.839.



(A) (B)

Fig. 7. Simple linear regression (SLR) analysis to estimate the linear relationship between the average annual appearance of whale sharks (WS) and the average sea surface temperature (SST) (A); and surface concentration of chlorophyll-*a* (Chl-*a*) in Botubarani waters (B)

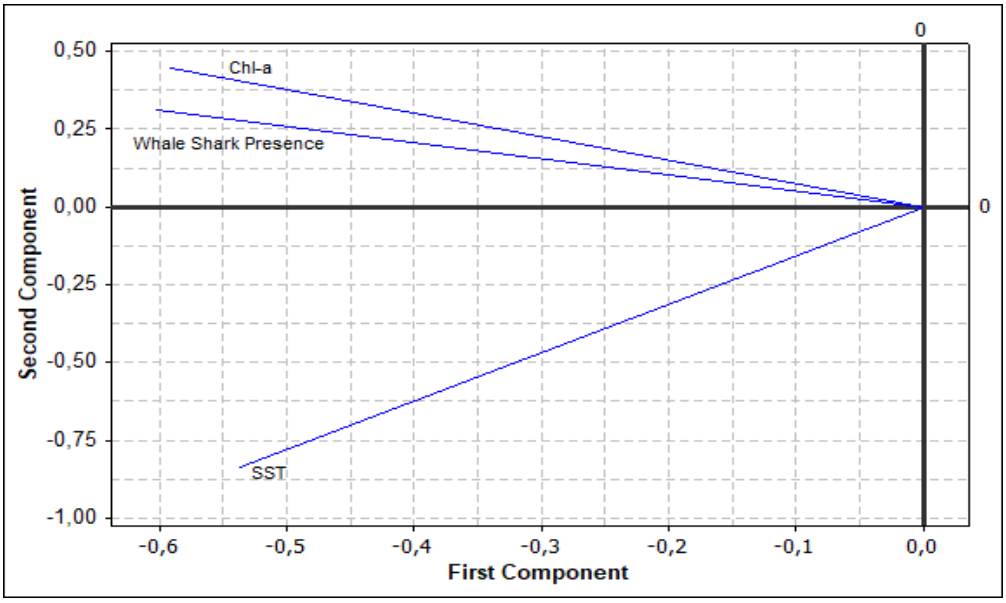


Fig. 8. Multivariate analysis through dimensionality reduction method using Principal Component Analysis to construct two new principal components by transforming whale shark presence, SST, and Chl-*a* variable data sets

DISCUSSION

Whale sharks generally require extensive cross-border migration in search of food **(Brunnschweiler *et al.*, 2009)**, mates **(Clingham *et al.*, 2016)**, and suitable habitats **(Hoffmayer *et al.*, 2021)**. However, this species is reported to appear in waters near the coast of Indonesia seasonally every year, including coastal waters in Botubarani, making it a destination area for marine tourism attraction **(Rahman *et al.*, 2017; Imam *et al.*, 2019; Kapinangasih *et al.*, 2022; Geopark Gorontalo, 2023)**.

Globally, around 25 major sites are whale shark aggregation areas. Indonesian waters are generally the densest areas for their distribution and appearance, even though they are not part of the main aggregation sites **(Copping *et al.*, 2018)**. There was a great increase in recreational diving and boating activity by visits from countries around the world that has led to discoveries of whale shark appearance of *Rhincodon typus* species in several places in Indonesian waters, including in Botubarani waters **(Stevens, 2007; Nugraha *et al.*, 2020)**. The proximity of whale sharks to the shoreline in Botubarani since 2016 has made this area an appealing tourist destination for both local and international visitors **(Djunaidi *et al.*, 2021)**. This natural attraction of whale shark sightings has gained popularity among tourists, who engage in activities such as boating, snorkeling, and diving to observe these magnificent creatures in the coastal waters of Botubarani, located in the Tomini Gulf of Gorontalo, Indonesia. The presence of whale sharks significantly correlates with ecotourism endeavors and marine conservation initiatives. Hence, the whale shark population in Indonesia is granted complete protection under Ministerial Decree No. 18/2013. In accordance, the regional government of Gorontalo designates specific protected zones by the Coastal Zone and Small Islands Zoning Plan (RZWP3K) for whale shark tourism **(Geopark Gorontalo, 2023)**, as shown in Fig. (1). The government, as the manager of the activities of visiting tourists, has also formed local tourism awareness groups and issued several supporting tools for ecotourism activities **(Handoko *et al.*, 2016)**, supporting the management framework of ecotourism co-management for whale sharks.

Most sources in the field do not know precisely when the whale shark first appeared in Gorontalo waters. Some local fishermen only informed them that whale sharks had long inhabited Gorontalo waters. **Sino *et al.* (2016)** and **Mile *et al.* (2017)** stated that the presence of whale sharks in Botubarani began to attract attention around the 2010s when tourists and divers started visiting the area to see whale sharks in person. There are allegations that fishermen or residents have known about the existence of whale sharks in Botubarani for a long time. The safe movement of the whale sharks and their intensive contact with humans illustrate the interaction between the marine megafauna and humans. For instance, the tour guide calls whale sharks to the water's surface by tapping on the boat's sides while feeding small shrimps. Although further research is needed, local fishermen stated that 53 individual whale sharks have inhabited the Botubarani waters for a prolonged time. Still, their appearance needs to be synchronized at the same time. Fishermen estimate the length of individual whale sharks to be 3 to 4 m. The longest-size individuals reach a length of 7 m. The results of research conducted by **Nugraha *et al.* (2016)** also reported that direct underwater observations conducted in April 2016 in Botuborani waters found five whale sharks measuring between 3-8 m. **Rosalina *et al.* (2021)** reported that in March 2020, in Botubarani waters, 11 individual whale sharks were identified with an average size range of 6–6.7 m. Another relevant research conducted by **Rombe *et al.* (2022)** from March to June 2021 identified the

length of the whale sharks that emerged to the surface of the waters of Botubarani Beach as many as 20 individuals ranging from 4 to 6.8m.

Our results for local analysis support other studies regarding the significant association between depth and bathymetric slope on the appearance and aggregation of whale sharks **(Copping *et al.*, 2018; Syah *et al.*, 2018)**. Similarly, the current study supports previous observations of whale shark appearance behavior in Botubarani waters by **Rahman *et al.* (2017)**, who reported the habits of whale sharks emerging from a depth of >100m, which feed through a rotating swimming mechanism at a depth of 15- 20m in the eco-tourism zone (whale shark appearance attraction area) near the coastline. Our current research through the development of 3D bathymetry models shows that such habitual mechanism of behavior is made possible by the presence of a seafloor split profile in the study area, extending diagonally in the southwest in the RZW3P area with a depth of ~ 400m to the ecotourism zone of the conservation area in the northeast which has a depth of ~ 5 to 60m (Figs. 3, 4). The unique feature of a split bottom in Botubarani's waters is also found at the bottom of the South Leato waters. Thus, such an area is an installation area beside Botubarani from the instrument of acoustic signal-transmitting markers on the Whale Sharks, which is the habitat for whale sharks **(Handoko *et al.*, 2017, 2019)**. The emergence of whale sharks is influenced by differences in hydrostatic pressure in the surface zone due to variations in the bathymetry profile and currents that occur around the area of their appearance **(Syah *et al.*, 2018; Pattiasina, 2020; Maruanaya *et al.*, 2022)**. The following are some of the arguments by which coastal geomorphology can influence the presence of whale sharks.

Whale sharks are able to live in various water temperatures. **Holland *et al.* (1999)** demonstrated that warmer water temperatures can influence whale shark migration by moving farther North when water temperatures are warmer than normal. A study of whale shark presence on the coast of California suggested that the presence of great white whale sharks is higher during periods of the year when ocean temperatures are cooler, possibly due to the movement of their prey into cooler areas, thus attracting whale sharks to follow **(Sims *et al.*, 2008; Gallagher *et al.*, 2014)**. However, the presence of whale sharks is also influenced by many other factors, such as food availability, weather, and human activities. For example, shrimp waste, which is introduced periodically from shrimp factory activities and feeding by tourists, can also be considered as another factor supporting the emergence of whale sharks in the waters. Therefore, the relationship between whale sharks and water temperature cannot be considered as the sole factor determining the presence of whales in a particular area.

Although it is not necessarily concluded that Chl-*a* concentrations influence the appearance of whale sharks, this data trend is indirectly related to the availability of the whale shark's main food, which is illustrated by trends in water surface Chl-*a* concentrations. Chlorophyll-*a* is a pigment found in phytoplankton which is a food source for zooplankton, small fish, and whale sharks. Being the predominant pigment in

phytoplankton cells, chlorophyll-*a* has long been used as a proxy for estimating the standing stocks of phytoplankton biomass in the water column **(Kadim *et al*., 2019)**. Although in-depth research is needed to answer the complexity of the relationship between phytoplankton and zooplankton in waters, further discussion in this study assumes that there is a positive correlation between Chl-*a* and zooplankton as the whale shark's main food. The research results by **Al-Najjar *et al*. (2003)** revealed a similar pattern of monthly surface chlorophyll-*a* distribution to total surface zooplankton biomass in the Gulf of Aqaba. The results of the study by **Stevens *et al*. (2000**) on whale sharks in the Antarctic region showed that the availability of food as measured by chlorophyll-*a* content affected the presence of whale sharks.

Research conducted by **Nelson and Eckert (2007)** in Bahía de Los Angeles, Baja California Norte, Mexico, showed that about 80% of whale sharks found feeding at depths ≤ 10 m (7.0±5.5m) are considered to be related to the high abundance of plankton at depths between 0- 10m, where sunlight can still penetrate and photosynthesis can still take place. The study conducted by **Croll *et al*. (2005)** in the California region showed that the presence of whale sharks is related to food availability including chlorophyll-*a* content.

This paper focused on the presence of whale sharks in Botubarani waters and their relationship with oceanographic and geomorphological characteristics. This study aimed to describe the local habitat of whale sharks from a geomorphological aspect and to determine whether there is a relationship between sea surface temperature (SST) and surface chlorophyll-*a* (Chl-*a*) concentrations with the appearance of whale sharks. This study used a combination of literature review, observation, interviews, and documentation to collect data, which were then analyzed using ArcGIS software. Although this study provides valuable insight into the factors influencing the presence of whale sharks in Botubarani waters, it has several limitations. First, this study only focuses on the relationship between SST and Chl-*a* and the presence of whale sharks. Future studies should consider many factors to gain a more comprehensive understanding of the determinants of the arrival of whale sharks in Botubarani waters. Second, the study only covers the period 2016 to 2021, and data were collected via secondary sources, which may have limitations in terms of completeness. This study recommends primary continuous data collection to gain a more accurate and comprehensive understanding of effective ecotourism area management of the research area. Lastly, although this study used a combination of methods to collect and analyze 3D bathymetric profile data of the study area, it has been entirely satisfactory in identifying and describing the unique local geomorphology of the study area as an emergence habitat. However, our research recommends that future studies consider using more advanced techniques for bathymetric analysis to gain a more comprehensive understanding of the study area. It can include multibeam sonar, LiDAR, or satellite-based bathymetry mapping techniques. These techniques can provide more detailed and accurate information regarding the bathymetry

of the study area, which can help researchers better understand the factors that influence the presence of whale sharks in the waters of Botubarani.

This paper focuses on the presence of whale sharks in the Ecotourism Development Zone in Botubarani waters and their relationship with oceanographic and geomorphological characteristics. This study aimed to describe the local habitat of whale sharks from a geomorphological aspect and determine whether there is a relationship beetween sea surface temperature (SST) and surface chlorophyll-*a* (Chl-*a*) concentrations with the appearance of whale sharks. This study used a combination of literature review, observation, interviews, and documentation to collect data, which were then analyzed using ArcGIS software.

Although this study provides valuable insight into the factors influencing the presence of whale sharks in Botubarani waters, it has several limitations. First, this study focused only on the relationship among SST and Chl-*a* and the presence of whale sharks. Future studies should consider many factors to gain a more comprehensive understanding of the determinants of the arrival of whale sharks in Botubarani waters. Second, the study only covers the period 2016 to 2021, and data was collected via secondary sources, which may have limitations in terms of completeness. This study recommends primary continuous data collection to gain a more accurate and comprehensive understanding of effective ecotourism area management of the research area. Lastly, although this study used a combination of methods to collect and analyze 3D bathymetric profile data of the study area, it has been entirely satisfactory in identifying and describing the unique local geomorphology of the study area as an emergence habitat. However, our research recommends that future studies consider using more advanced techniques for bathymetric analysis to gain a more comprehensive understanding of the study area. It can include multibeam sonar, LiDAR, or satellite-based bathymetry mapping techniques. These techniques can provide more detailed and accurate information regarding the bathymetry of the study area, which can help researchers better understand the factors that influence the presence of whale sharks in the waters of Botubarani.

CONCLUSION

This research indicated surface chlorophyll-*a* (Chl-*a*) concentrations as the primary consideration influencing the presence of whale sharks in the Botubarani Ecotourism Development Zone. Spatially, the specific occurrence frequency is close to the shoreline and supports the emergence of habitat, thoroughly related to the unique seafloor profile as a characteristic of Botubarani waters bathymetric. The steep deep cleft promotes whale shark presence near the coastline, with unique seafloor features, sheltered reefs, and coral/algae habitats. This model may vary in several water areas in Indonesia and worldwide. Furthermore, this research implies that alterations in the migratory behavior of whale sharks are possible. However, the assumption requires data over a more extended period, including the involvement of more complex observational variables.

REFERENCES

Allen C.A. (2020). Imagery, maps and monitoring of the world's tropical coral reefs. Zenodo. DOI: https://doi.org/10.5281/zenodo.3833242. Cited 5 Aug 2023.

Al-Najjar, T.; Badran, M. and Al-Zibdeh, M. (2003). Seasonal cycle of surface zooplankton biomass in relation to the chlorophyll *a* in the Gulf of Aqaba, Red Sea. Abhath Al-Yarmouk: Basic Sci. & Eng, 12(1): 109-118.

Baderan, D.W.K.; Lamuka, A.P. and Nasila, W.P. (2023). Inventory of whale shark (*Rhincodon typus*) in Botubarani Village, Kabila Bone District, Bone Bolango Regency, Gorontalo Province (Indonesian). Mitita J. Penelit., 2(1): 43-49.

Block, B.A.; Jonsen, I.D.; Jorgensen, S.J.; Winship, A.J.; Shaffer, S.A.; Bograd, S.J. and Costa, D.P. (2011). Tracking apex marine predator movements in a dynamic ocean. Nature, 475(7354): 86-90. DOI: https://doi.org/10.1038/nature10082.

Botubarani Whale Shark Site. (n.d.). Botubarani Whale Shark Site. https://geopark.gorontaloprov.go.id/sites/daftar-biosite/botubarani-whale-shark-site/. Retrieved 5 August 2023.

Brunnschweiler, J.M.; Baensch, H.; Pierceand, S.J. and Sims, D.W. (2009). Deep-diving behavior of a whale shark *Rhincodon typus* during long-distance movement in the western Indian Ocean. J. Fish. Biol., 74(3): 706-714. DOI: https://doi.org/10.1111/j.1095-8649.2008.02155.x.

Convention on International Trade In Endangered Species of Wild Fauna and Flora (CITES). (2023). Rhincodontidae Whale Sharks. https://cites.org/sites/default/files/eng/app/2021/E-Appendices-2021-06-22.pdf. Cited 5 August 2023.

Clingham, E.; Brown, J.; Henry, L.; Beardand, A. and Dove, A.D. (2016). **Evidence** that St. Helena island is an important multi-use habitat for whale sharks, *Rhincodon typus*, with the first description of putative mating in this species. PeerJ Preprintse, 1885v1. DOI: 10.7287/peerj.preprints.

Copping, J.P.; Stewart, B.D.; Colin, J.M.; Jamesand, H. and Richard, R. (2018). Does bathymetry drive coastal whale shark (i) aggregations?. PeerJ, 6: e4904.

Croll, D.A.; Tershy, B.R.; Hewitt, R.P.; Demer, D.A.; Fiedler, P.C.; Smith, S.E.; Armstrong, W.S.; Popp, J.B. and Kiefer, D.A. (2005). An integrated approach to the foraging ecology of marine birds and mammals**.** Deep Sea Research Part II: Topical Studies in Oceanography**,** 52(3-4): 429-462.

Decree of the Minister of Maritime Affairs and Fisheries Number 18 of 2013. https://peraturan.bpk.go.id/Details/159977/kepmen-kkp-no-18kepmen-kp2013-tahun-2013

Djunaidi, A.; Jompa, J.; Nadiarti, N.; Baharand, A. and Tilahunga, S.D. (2021). Benefit sharing from whale shark tourism in Botubarani, Gorontalo and Labuhan Jambu, Teluk Saleh. Proceeding of the 2nd International Symposium Marine Resilience and Sustainable Development in South Sulawesi, Indonesia, 2020: 1-10 DOI: 10.1088/1755-1315/763/1/012063.

Esri Indonesia. "Kawasan Konservasi Sulawesi" [Web Map]. Scale Not Given. **Peta** interaktif kawasan konservasi di wilayah kerja BPSPL Makassar. https://www.arcgis.com/apps/View/index.html?appid=271fe9f0e415473393ec520dbdc7e8c6. Retrieved 20 May 2023.

Gallagher, A.J.; Serafy, J.E.; Cooke, S.J.; Hammerschlagand, N. and Haddad, N.M. (2014). Influences of temperature and behaviour on bathymetric distributions of deepwater Caribbean reef fishes. Mar. Ecol. Prog. Ser., 509: 245-256.

Geopark Gorontalo (2023). https://geopark.gorontaloprov.go.id/sites/daftar-biosite/botubarani-whale-shark-site/.

Guzman, H.M.; Gomez, C.G.; Hearnand, A. and Eckert, S.A. (2018). Longest recorded trans-Pacific migration of a whale shark (*Rhincodon typus*). Mar. Biodivers. Rec., 11(1): 1-6.

Handoko, K.; Himawan, M.R.; Tania, C.; Syarifuddin, U.; Jakasukmana, M. and Maduppa, H. (2016). Whale sharks at Botubarani Beach, Gorontalo (Indonesian). Balai Pengelolaan Sumberdaya Pesisir dan Laut Makassar, Makassar. Indonesia. 119 pp.

Handoko, K.; Sukmoputro, R.A.I.; Himawan, M.R. and Tania, C. (2017). Characteristics of population Hiu Paus (*Rhincodon typus*) and pattern of behavior stay at the Beach Botubarani, Bone Bolango, Gorontalo. Coastal and Ocean J., 1(2): 169-178.

Handoko, K.; Sukmoputro, R.A.I.; Himawan, M.R. and Tania, C. (2019). Appearance pattern of whale sharks (*Rhincodon typus*) in Botubarani waters, Gorontalo (Indonesian). Proceedings of the 2nd Indonesian Stingray Shark National Symposium in Indonesia, 2018: 49-56.

Hoffmayer, E.R.; McKinney, J.A.; Franks, J.S.; Hendon, J.M.; Driggers, W.B.; Falterman, B.J. and Byrne, M.E. (2021). Seasonal occurrence, horizontal movements, and habitat use patterns of whale sharks (Rhincodon typus) in the Gulf of Mexico. Fron. Mar. Sci., 7: 598515.

Holland, K.N.; Wetherbee, B.M.; Peterson J.D. and Lowe. C.G. (1999). Movements of tiger sharks (Galeocerdo cuvier) in coastal Hawaiian waters. Mar. Biol., 134(4): 665-673. DOI: https://doi.org/10.1007/s002270050582.

Pierce, S.J. and Norman, B. (2016). Rhincodon typus. The IUCN Red List of Threatened Species 2016. https://www.iucnredlist.org/search?query=whale%20shark&searchType=species. Cited 5 August 2023.

Ihsan, E.N.; Enita, S.Y. and Wirasatriya, A. (2018). Oceanographic factors in fishing ground location of anchovy at Teluk Cenderawasih National Park, West Papua: are these factors have an effect of whale sharks appearance frequencies?. Proceeding of the 3rd International Conference on Tropical and Coastal Region Eco Development in Yogyakarta, Indonesia, 116: 1-9. DOI: 10.1088/1755-1315/116/1/012017.

Imam, D.; Kamal, M.M. and Fachrunnisa, R. (2019). Human-Whale Shark Interaction: An Inquiry into Standard Operational Procedure (SOP) for Tourist in Papua and East Java. Proceeding of International Conference on Life Sciences and Technology in Malang, Indonesia, 276: 1-14. DOI: 10.1088/1755-1315/276/1/012030.

Ina Geoportal. https://tanahair.indonesia.go.id/portal-web/diakses pada 05/08/2023

Indonesian Geospatial Board (2023). https://tanahair.indonesia.go.id/portal-web/

JPL/OBPG/RSMAS. (2020). MODIS Terra L2P swath SST data set. Ver. 2019.0. PO.DAAC, CA, USA. DOI: https://doi.org/10.5067/GHMDT-2PJ19. Cited 20 May 2023.

Kadim, M.K.; Pasisingi, N. and Arsyad, S. (2019). Horizontal distribution of chlorophyll-a in the Gorontalo Bay. Nat. Environ. Pollut. Technol., 1381-1385.

Kapinangasih, P.; Wijayanti, D.P. and Sabdono, A. (2022). Behavior and appearance of whale sharks (*Rhincodon typus*, Smith 1828) at Bentar Beach, Probolinggo (Indonesian). J. Mar. Res., 11(1): 49-60. DOI: https://doi.org/10.14710/jmr.v11i1.31727.

Kennedy, E.V.; Chris, M.R.; Mitchell, B.L.; Kovacs, E.M.; Acevedo, R.B.; Roe, M. and Phinn, S.R. (2021). Reef cover, a coral reef classification for global habitat mapping from remote sensing. Scientific Data, 8(1): 1-20. DOI: https://doi.org/10.6084/m9.figshare.14397182.

Kumari, B. and Raman, M. (2010). Whale shark habitat assessments in the northeastern Arabian Sea using satellite remote sensing. Int. J. Remote Sens., 31(2): 379-389. DOI: https://doi.org/10.1080/01431160902893444.

Luschi, P. (2013). Long-distance animal migrations in the oceanic environment: orientation and navigation correlates. Int. Sch. Res. Not. Zoology., 2013: 1-23. DOI: 10.1155/2013/631839.

Marcus, L.; Virtue, P.; Pethybridge, H.R.; Meekan, M.G.; Thums, M. and Nichols, P.D. (2016). Intraspecific variability in diet and implied foraging ranges of whale sharks at Ningaloo Reef, Western Australia, from signature fatty acid analysis. Mar. Ecol. Prog. Ser., 554: 115-128. DOI: https://doi.org/10.3354/meps11807.

Maruanaya, Y.; Retraubun, A.; Tuhumury, S.F and Abrahamzs, J. (2022). Feeding habits and frequency of appearances of whale sharks (*Rhincodon typus*) in Kwatisore Waters in the Customary Rights of Akudiomi Village in Cenderawasih Bay National Park (Indonesian). J. Ilmu Teknol. Kelaut. Trop., 14(1): 109-129. DOI: http://dx.doi.org/10.29244/jitkt.v14i1.39648.

Mile, I.; Kasim F. and Nursinar, S. (2017). Community perception and participation in the management of whale shark tourism (Indonesian). Nike: J. Ilmiah Perikan. Kelaut., 5(1): 1-7. DOI: https://doi.org/10.37905/.v5i1.5263.

NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. Moderate-resolution Imaging Spectroradiometer (MODIS) Terra Chlorophyll Data; 2023 Reprocessing. NASA OB.DAAC, Greenbelt, MD, USA. DOI: 10.5067/TERRA/MODIS/L3M/CHL/2018.

Nelson, J.D. and Scott, A.E. (2007). Foraging ecology of whale sharks (*Rhincodon typus*) within Bah´Ia de Los Angeles, Baja California Norte, Mexico. Fisher. Res., 84: 47–64. DOI: https://doi.org/10.1016/j.fishres.2006.11.013.

Nugraha, Y. and Rudi, A. (2016). Observation of the appearance of whale sharks (*Rhincodon typus*) around the waters of Tomini Bay, Gorontalo Province(Indonesian). Bul. Teknik Litkayasa Sumberd. Penangkapan., 14(1): 53–5. DOI: http://dx.doi.org/10.15578/btl.14.1.2016.53-55.

Nugraha, B.; Dharmadi, D. and Wiadnyana, N.N. (2020). Status of utilization and efforts to handle stranded whale shark (*Rhincodon typus*) in Indonesian Waters (Indonesian). J. Kebijak. Perikan. Indonesia., 12(1): 47-57. DOI: http://dx.doi.org/10.15578/jkpi.12.1.2020.47-57.

Pattiasina, T.F. 2020. A review of the concept and application of geospatial technology in mapping and modeling the migration of whale shark (*Rinchodon typus*). Musamus Fisher. Mar. J., 2(2): 77-101.

Rahman, A.; Haryadi, J.; Sentosa, A.A. and Mujiyanto, M. (2017). Early study of whale shark (*Rhyncodon typus*, Smith 1828) appearance in Tomini Bay linked to physical and biological factors in the waters (Indonesian). Akuatika Indonesia, 2(2): 128-137.

Ranintyari, M.; Syamsuddin, M.L. and Astuty, S. (2018). Effects of oceanographic factors on spatial distribution of Whale Shark in Cendrawasih Bay National Park, West Papua. Proceeding of the4th International Symposium on LAPAN-IPB Satellite for Food Security and Environmental Monitoringin Bogor, Indonesia,149: 012050. DOI: http://dx.doi.org/10.1088/1755-1315/149/1/012050.

Rombe, K.H.; Amiluddin, M.; Surachmat, A.; Noer, A.; Rahman, A. and Rosalina, D. (2022). Monitoring of whale sharks (*Rhyncodon typus*) in the waters of Botubarani Beach, Kabila Bone District, Bone Bolango Regency, Gorontalo Province (Indonesian). Jurnal Kelautan: Indonesian J. Mar. Sci. Technol, 15(3): 216-225. DOI: https://doi.org/10.21107/jk.v15i3.14021

Rombe, K.H.; Agus. and Melda, S. (2021). Seawater quality parameters in whale shark tourism area in Bontubarani Waters, Gorontalo Province. Berk. Perikan. Terubuk., 49(2): 930-936. DOI: http://dx.doi.org/10.31258/terubuk.49.2.930-936

Rosalina, D.; Arafat, Y.; Anjaya, I. and Jamil, K. (2021). Monitoring of whale sharks (*Rhyncodon typus*) in the waters of Botubarani Village, Kabila Bone District, Bone Bolango Regency, Gorontalo Province (Indonesian). Aquat. Sci: J. Ilmu Perair., 3(2): 9–16.

Sequeira, A.M.; Mellin, C.; Floch, L.; Williams, P.G and Bradshaw, C.J. (2014). Inter-ocean asynchrony in whale shark occurrence patterns. J. Experimen. Mar. Biol. Ecol., 450: 21-29. DOI: https://doi.org/10.1016/j.jembe.2013.10.019.

Sims, D.W.; Southall, E.J.; Humphries, N.E.; Hays, G.C.; Bradshaw, C.J.; Pitchford, J.W. and Quayle, V.A. (2008). Scaling laws of marine predator search behaviour. Nature., 451(7182): 1098-1102. DOI: https://doi.org/10.1038/nature06518.

Sino, A.R.; Kasim, F. and Hamzah, S.N. (2016). Evaluation of whale shark ecotourism in Botubarani Village (Indonesian). J. Ilm. Perikan. Kelaut., 4(4): 132-139. DOI: https://doi.org/10.37905/.v4i4.5074.

Stevens, J.D.; Bonfil, R.; Dulvy, N.K. and Walker, P.A. (2000). The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES J. Mar. Scie.: J. du Conseil., 57(3): 476-494. DOI: https://doi.org/10.1006/jmsc.2000.0724.

Stevens, J.D. 2007. Whale shark (*Rhincodon typus*) biology and ecology: A review of the primary literature. Fisher. Res., 84(1): 4–9. DOI: 10.1016/j.fishres.2006.11.008

Syah, A.F.; Musrifah, M. and Cahyono, H. (2018). Modeling of potential whale shark (*Rhincodon typus*) areas using remote sensing data in Probolinggo Waters, East Java (Indonesian). J. Penelit. Perikan. Indonesia., 24(3): 209-216. DOI: http://dx.doi.org/10.15578/jppi.24.3.2018.209-216