Occurrence of whale sharks (*Rhincodon typus*) based on environmental characteristics in the waters of Botubarani Beach, Gorontalo

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Abstract. Whale sharks are megafauna that inhabit tropical and warm subtropical seas as filter feeders and prey on small-sized organisms by filtering seawater. Environmental factors, such as sea surface temperature (SST), salinity (Sal), chlorophyll-a (Chl-a), ocean surface currents (currents), and the abundance of certain small marine biota, play a role in the appearance of whale sharks. This study aimed to analyze the oceanographic factors influencing whale shark appearance. Whale shark occurrence data were collected between June 2022 and July 2024. The number of whale sharks appearing in the waters of Botubarani Beach in 2022, 2023, and 2024 were 224, 337, and 219, respectively. Principal Component Analysis (PCA) was used to identify the most influential oceanographic parameters affecting whale shark occurrence. The seasonal averages of several environmental parameters in the waters of Botubarani Beach, aligned with the whale shark appearance periods, were as follows: sea surface temperature (SST) 20.03 °C, salinity 33.35 PSU, chlorophyll-a, 0.135 mg/m^3; and surface current speed 0.16 m/s. PCA results indicate that the most influential environmental oceanographic parameters on whale shark occurrence at Botubarani Beach are the surface current velocity and surface chlorophyll-a concentration.

Keywords: Botubarani waters, occurrence, Whale Shark

1 Introduction

The whale shark is a megafauna species that inhabits tropical and warm seas [1]. Whale sharks have long migration ranges and appear at several locations across tropical waters [2]. Their presence has been confirmed at several locations in Indonesia, such as Cenderawasih Bay, Sumbawa, Berau, and Gorontalo [3,4]. In some locations in Indonesia, whale shark

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sightings have been utilized for ecotourism activities [3,5]. The large size and gentle nature of whale sharks make them attractive to tourists for direct observation [4]. Environmental factors, such as sea surface temperature abundance, salinity, chlorophyll-a, ocean surface currents, and the abundance of small organisms, such as zooplankton and small pelagic fish, play an important role in the occurrence of whale sharks [6].

The whale shark is a filter feeder that consumes small organisms by filtering the seawater [7]. The presence of zooplankton and small fish as the main food source of whale sharks is closely related to the primary productivity produced by phytoplankton. Oceanographic factors such as currents influence the distribution of phytoplankton and ultimately affect the occurrence of whale sharks [8,9].

Whale shark ecotourism also has anthropogenic impacts. Tourist interactions that do not comply with regulations, such as touching or riding whale sharks, can affect the behavior of animals [10]. As whale sharks move relatively slowly, they are vulnerable to boat strikes, which can cause severe injuries [11]. Several studies have shown that behavioral changes in whale sharks due to human disturbance can negatively affect their reproduction and migration patterns [12]. Whale sharks affected by anthropogenic impacts show different swimming behaviors compared to those under normal conditions, with their movement and swimming style being disrupted [1].

The occurrence of whale sharks in the waters of Botubarani Beach has been recorded since 2016, and has driven the growth of local tourism. This study aims to analyze oceanographic factors influencing whale shark appearance, assess the impact of anthropogenic activities on their behavior, and explain the relationship between these two influences on whale shark presence and behavior.

2 Materials and methods

2.1 Study area

This research was conducted at Botubarani Beach, Bone Bolango Regency, Gorontalo Province (**Fig. 1**). The study period was from February 2024 to April 2024.

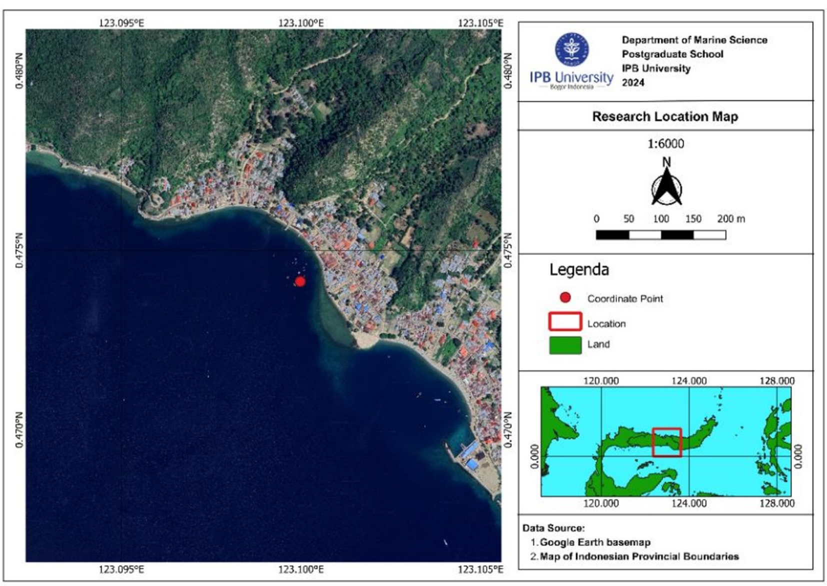

Fig. 1. Location of Botubarani Waters, Gorontalo.

2.2 Data acquisition

Whale shark data were collected using the stereo-diver-operated video (stereo-DOV) method, which enables the accurate measurement of whale shark behavior. Divers operated the stereo-DOV system to record the presence and activity of whale sharks [13,14]. Three months of direct observation identified four individuals. Each individual appearing was identified with the help of data provided by tourism management authorities. Data collection was conducted daily with the assistance of local fishermen and relevant organizations responsible for the tourism area.

Oceanographic data were obtained from https://marine.copernicus.eu/ to collect information on sea surface temperature, sea surface salinity, ocean currents, and chlorophyll-a. Sea surface temperature data were measured using a thermometer. The oceanographic data collection points were determined based on the whale shark sighting locations in the tourist area. The collected data were then analyzed to understand the environmental conditions influencing whale shark occurrence and behavior.

2.3 Data analysis

Data analysis was carried out using a descriptive method to illustrate the pattern of whale shark occurrence based on oceanographic parameters [15]. Principal Component Analysis (PCA) was used to identify the dominant oceanographic factors influencing whale shark occurrence. PCA was applied to reduce the dimensionality of various environmental variables, such as temperature, salinity, chlorophyll-a, and currents, thereby determining the key parameters contributing to the whale shark distribution.

Whale shark movements will be observed following the guidelines issued by [16] to identify the behaviors shown by whale sharks toward approaching tourists [16]. Non-threatening behaviors toward humans are also analyzed when whale sharks interact with tourists [17]. Each movement was recorded, photographed using a camera, and observed in detail to better understand their movements. An evaluation of approximately 554 photos and 64 videos of whale sharks from over 100 dives/interactions between February 12, 2024, and April 30, 2024 (approximately three months of observation) in the waters around Botubarani was conducted to specifically document whale shark behavior.

The relationship between environmental parameters and whale shark occurrence was analyzed using Principal Component Analysis (PCA). This analysis is based on contingency table data linking oceanographic parameters with whale shark occurrence. The data matrix consists of the number of whale shark sightings (rows) and oceanographic parameters, such as sea surface temperature (SST), salinity, chlorophyll-a, and surface currents (columns).

3 Results and discussion

Whale sharks in the waters of Botubarani Beach appear almost daily throughout the year (**Fig. 1**). Records show that whale shark sightings in Botubarani have been documented since 2016, with 164 occurrences within a 12-month period. Information from whale shark management authorities indicates that factory waste disposal and the provision of shrimp skins and heads in 2016 were the main triggers for the appearance of the first whale shark in the surface waters of Botubarani Beach. Factors influencing whale shark occurrence are thought to include the amount of shrimp processed at the factory, as well as oceanographic conditions such as sea surface temperature, sea surface salinity, surface currents, and chlorophyll-a, which are suspected to play a role in whale shark movement.

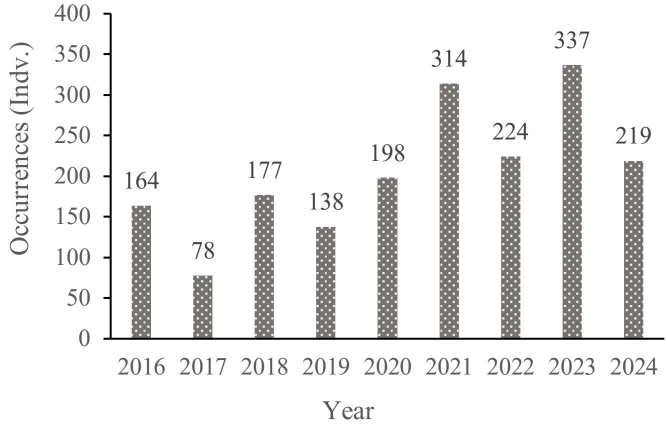

Fig. 2. Whale shark occurrences from 2016 to 2024 in Botubarani Coastal Waters.

The highest number of whale shark sightings in the waters of Botubarani Beach occurred in 2023, with 337 occurrences. The lowest number of occurrences (78) was recorded in 2017. The number of whale sharks was counted based on the number of individuals appearing for the first time. The whale sharks appeared between 06:00 and 18:00. Fishermen serving as tour guides paddle their boats to the whale shark interaction zone and tap their boats with paddles at 06:00 WITA to attract sharks. Individuals that appear are fed small shrimp (krill), encouraging them to remain for a certain period. Whale sharks were identified by spot patterns on their bodies to distinguish one individual from another [18]. An individual appearing for the first time was recorded as a single occurrence. The total number of whale shark occurrences was determined by the number of different individuals that appeared. A total of 219 whale sharks appeared in the waters of Botubarani Beach between January and August 2024. **Fig. 3** illustrates the monthly occurrences of whale sharks. The number of whale shark sightings is influenced by environmental factors, such as oceanographic conditions and the presence of predators, such as orcas, in March and June. Orcas are marine mammals that migrate through the Gorontalo Bay. Sharks and orcas are apex predators; therefore, if two species meet in the same area, interspecific competition can occur [19]. The presence of orcas causes whale sharks to move to safer locations away from orca migration routes.

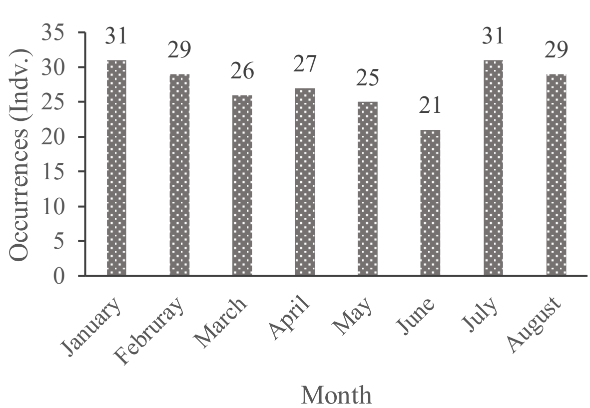

Fig. 3. Whale shark occurrences in 2024.

The whale sharks appearing in the waters of Botubarani Beach range in size from 4.5 to 6 m (**Table 1**). All whale sharks identified in this area were males. The data show that whale sharks appear almost daily throughout the year, with the highest occurrence in January and July. Oceanographic factors such as temperature and chlorophyll-a contribute to this pattern. Five different individuals were recorded during the data collection period, with daily sightings ranging from one to two individuals. The highest number of whale shark occurrences was recorded in January and July, whereas the lowest was recorded in June. Whale sharks sometimes avoid motorboats by moving slowly toward the seabed. Engine noise from motorboats is suspected to disturb whale shark appearance as well as feeding and/or mating behavior. The use of motorboats in the Botubarani Beach area is minimal because they can disrupt interactions and sightings. Tourists interacting with whale sharks use paddle boats. Boat tours are the most popular activities among visitors, compared to surface swimming or diving, as they require no special skills. Feeding from the boat allows close interaction with whale sharks[20]. Four whale shark individuals were identified. One individual could not be identified because its appearance was far from the data collection location. Each whale shark individual has a different size: WS-GT-01 measures 4.5 meters, WS-GT-02 measures 5 meters, WS-GT-03 is the smallest at 3.5 meters, and WS-GT-04 is the largest at 6 meters.

Table 1. Photo identification and size of individual whale sharks in Botubarani coastal waters.

Individual	Size Estimation (m)	Photo ID
WS-GT-01	4,5	
WS-GT-02	5	
WS-GT-03	3,5	

Individual	Size Estimation (m)	Photo ID
WS-GT-04	6	

The whale shark is a large species, but generally a slow swimmer, using a swaying propulsion movement that involves most of the body behind the pectoral fins. Juvenile and adult whale sharks typically swim at speeds of 0.05–1.0 m/s and can maintain this speed for hours [21]. Whale shark behavior in Botubarani includes circling (swimming around the interaction zone), gradual changes, abrupt changes, banking, and vigorous body shuddering.

In general, whale sharks most frequently exhibit abrupt changes in behavior when tourists, such as divers or swimmers, touch them. Whale sharks in the waters of Botubarani Beach generally rarely display behaviors categorized as "disturbed." The most commonly observed behaviors were gradual changes and circling. Unlike whale sharks, WS-GT-01, WS-GT-02, WS-GT-03, and WS-GT-04 appear less frequently. The sizes of WS-GT-03 and WS-GT-04 were smaller than those of WS-GT-01 and WS-GT-02. WS-GT-01, WS-GT-02, and WS-GT-03 were tagged, whereas WS-GT-04 was not tagged and was the least frequently sighted in the waters of Botubarani Beach.

Botubarani Beach is located in Tomini Bay and has oceanographic characteristics that influence whale shark behavior. Water conditions with temperatures ranging from 28–31°C, relatively stable salinity, and high productivity resulting from both human and natural nutrient inputs create an environment that supports whale shark feeding behavior and occurrences. The sea temperature, salinity, and chlorophyll-a levels in the waters of Botubarani tended to remain stable and showed no significant changes (**Table 2**). Sea surface temperature in the waters of Botubarani is influenced by oceanographic conditions such as currents, winds, and seasonal patterns.

Table 2. Sea surface temperature of Botubarani coastal waters from 2022 to 2024.

Month	Temperature (°C)		
	2022	**2023**	**2024**
January	-	29.69	30.3
February	-	29.54	30.19
March	-	30.15	30.35
April	-	30.29	30.68
May	-	30.43	30.66
June	30.26	30.22	30.06
July	29.7	29.67	29.54
August	29.46	29.3	-
September	30.97	29.02	-
October	30.13	29.58	-
November	30.41	30.64	-
December	29.97	30.59	-

Data obtained showed that sea surface temperatures in the waters of Botubarani from June to December 2022 ranged from 29.46°C to 30.97°C. The highest sea surface temperature was recorded in September, at 30.97°C, during which nine individual whale sharks were sighted in Botubarani waters. Research conducted in the same year reported a temperature range of 28.36°C to 30.29°C [22]. Tropical waters with a sea surface temperature (SST) exceeding 28°C are categorized as warm waters, which geographically represent the primary global distribution range of whale sharks [23]. Studies using MODIS and Landsat-8 satellite data have indicated that the sea surface temperature in this area exhibits seasonal variation. Temperatures tend to decrease during the first transitional season and the east monsoon (April–September) due to wind-driven upwelling, whereas during the west monsoon (October–March), temperatures rise as a result of warm currents from the Pacific Ocean. Research indicates that the wide distribution of whale sharks also suggests tolerance to varying temperatures, although they generally prefer warm waters [24]. There was a significant temperature drop in September, with the lowest temperature in 2023 at 29.02°C. The highest temperature was recorded in November at 32.15°C. The highest average sea surface temperature recorded in November 2021 was 30.29°C, marking the transition from the second monsoon to the west monsoon. The lowest average temperature occurred in August at 28.36°C, marking the period from the end of the east monsoon to the second transition season.

Whale sharks are widely distributed across warm tropical and subtropical waters, within a salinity range of 31.96–33.23 PSU [25]. These water conditions are believed to be ideal for supporting the growth of plankton and small-sized nektons, which are the main food sources of whale sharks. Such suitable conditions allow whale sharks to remain in these locations for a certain period.

Table 3. Sea surface salinity of Botubarani coastal waters from 2022 to 2024.

Month	**Salinity (PSU)**		
	2022	**2023**	**2024**
January	-	33.81	34.01
February	-	33.82	33.98
March	-	33.75	33.98
April	-	33.79	33.91
May	-	33.77	33.74
June	33.6	33.75	33.6
July	33.43	33.75	33.51
August	33.45	33.89	-
September	33.33	34	-
October	33.28	34.12	-
November	33.27	34.1	-
December	33.51	34.03	-

The lowest surface salinity was recorded in November 2022 at 33.27 PSU (**Table 3**). The period from August to November 2022 showed a decrease in salinity values in the Botubarani waters from 33.45 PSU to 33.27 PSU. The salinity value increased again in December, reaching 33.51 PSU. The surface salinity at the beginning of 2023, from January to July, tended to be more stable than that at 2022. The distribution of surface salinity from January to July 2023 ranged between 33.81 PSU and 33.75 PSU. The period from August to October 2023 showed an increase in surface salinity, rising from 33.89 PSU in August to 34.12 PSU in October. Compared to the surface salinity in December 2023 and January 2024, the surface salinity tended to remain stable. Surface salinity decreased from 33.98 PSU in March 2024 to 33.51 PSU in July. Surface salinity did not significantly affect the occurrence of whale sharks at Botubarani Beach. A 2001 study in Belize recorded an annual salinity range of 34.5 to 35.5 PSU[26]. Research in Botubarani conducted in 2017 showed that the salinity in Botubarani did not undergo significant changes, ranging from 31.96 33.23 PSU [25].

Table 4. Sea surface current of Botubarani coastal waters from 2022 to 2024.

Month	Surface Current (m/s)		
	2022	2023	2024
January	-	0.129	0.161
February	-	0.195	0.084
March	-	0.094	0.014
April	-	0.098	0.063
May	-	0.097	0.111
June	0.097	0.107	0.127
July	0.125	0.132	0.145
August	0.132	0.159	-
September	0.107	0.141	-
October	0.090	0.149	-
November	0.187	0.121	-
December	0.265	0.147	-

Ocean currents have a significant influence on the occurrence of whale sharks because they are directly related to the distribution of food sources and migration patterns of this species. Surface currents around the Botubarani waters have velocities ranging from 0.01 to 0.26 m/s (**Table 4**). From June to December, 2022, the average current velocity was 0.14 m/s. The lowest surface current velocity was recorded in October at 0.01 m/s, whereas the highest was recorded in December at 0.25 m/s. The surface current velocity in January 2023 decreased compared to that in December 2022. An increase in velocity occurred in February, reaching 0.19 m/s, before decreasing again in March to 0.09 m/s. In January 2024, the current velocity did not show a significant decrease compared with that in December 2023. A substantial decline occurred again in March, reaching as low as 0.01 m/s. The surface current velocity then steadily increased from April to July. A study conducted on Darwin Island showed that surface currents have a considerable influence on the occurrence of whale sharks in the area [12].

Chlorophyll-a concentration in a given water body strongly influences the occurrence of whale sharks. A study conducted by [4] on whale shark behavior in Probolinggo waters in relation to environmental factors showed that sea surface temperature and chlorophyll-a significantly affected whale shark occurrence patterns [4]. Research suggests that, in Botubarani, Gorontalo, the presence of whale sharks may be driven by food availability, particularly because of the high abundance of copepods and fish larvae in areas where whale sharks are frequently observed.

Upwelling frequently occurs in Tomini Bay, particularly around the Togean Islands and southern Gorontalo region, which are areas with strong indications of upwelling. This process leads to an increase in the chlorophyll-a concentration, rising from 0.134 mg/m³ in October to 0.146 mg/m³ in November. Two peaks in the chlorophyll-a concentration were recorded in March and September 2023. A study conducted in 2024 reported that upwelling will occur in September [22]. The upwelling phenomenon occurs when water masses from the northern region at a depth of approximately 150 m move and push the Maluku Sea water masses at the mouth of Tomini Bay, an area where whale sharks appear in Botubarani, toward the continental shelf. This interaction causes the deeper water masses to rise to the surface [27]. The chlorophyll-a concentration from January to April remained relatively consistent, with values of 0.139 mg/m³ in January and February, and 0.135 mg/m³ in April. An increase in the chlorophyll-a concentration was observed from May to July. The chlorophyll-a concentration in Botubarani is not markedly different from findings in other whale shark occurrence sites, such as Probolinggo [28] and the Eastern Pacific Ocean [2].

Table 5. Sea surface chlorophyll of Botubarani coastal waters from 2022 to 2024

Month	Surface Chlorophyll (m/s)		
	2022	2023	2024
January	-	0.138	0.139
February	-	0.149	0.139
March	-	0.153	0.137
April	-	0.15	0.135
May	-	0.145	0.144
June	0.134	0.144	0.159
July	0.135	0.142	0.203
August	0.14	0.148	-
September	0.139	0.151	-
October	0.134	0.144	-
November	0.146	0.143	-
December	0.144	0.138	-

The environmental parameters used to analyze their relationship with whale shark occurrence were sea surface temperature, salinity, chlorophyll-a, and surface currents. Data on whale shark sightings, temperature, salinity, chlorophyll-a, and surface currents were averaged seasonally (every three months). Each dataset was standardized beforehand to prevent any variable from dominating owing to differences in units or value ranges [29]. The whale shark occurrence values from P1 to P9 represent the average sightings for each season: Northwest Monsoon (December–February), Transitional Season I (March–May), Southeast Monsoon (June–August), and Transitional Season II (September–November) (**Table 6**).

Table 6. Environmental parameters affecting the seasonal occurrence of whale sharks in the waters of Botubarani Beach in June 2022 - July 2024 (*= three-monthly average value according to season).

Label	SST (°C)	Salinity (psu)	Chl -a (mg/m^3)	Surface Current (m/s)	Occurrence (Individual)
P1	29.807	33.493	0.136	0.118	29.33
P2	30.503	33.293	0.140	0.128	18.67
P3	29.733	33.713	0.144	0.196	29.33
P4	30.290	33.770	0.149	0.096	30.33
P5	29.730	33.797	0.145	0.133	29.33
P6	29.747	34.073	0.146	0.137	23.67
P7	30.360	34.007	0.139	0.130	29.67
P8	30.563	33.877	0.139	0.062	26.00

Label	SST (°C)	Salinity (psu)	Chl -a (mg/m^3)	Surface Current (m/s)	Occurrence (Individual)
P9	29.800	33.555	0.181	0.136	26.00

The distribution of environmental variables within the principal component space showed that the first axis (F1) explained 50.52% of the variation and the second axis (F2) explained 26.33%, with a total explained variance of 76.85%. The vector pattern indicates that salinity has a strong positive correlation with F2, while sea surface temperature (SST) is negatively correlated with F1. Surface currents and chlorophyll-a exhibited a more complex relationship with both principal components.

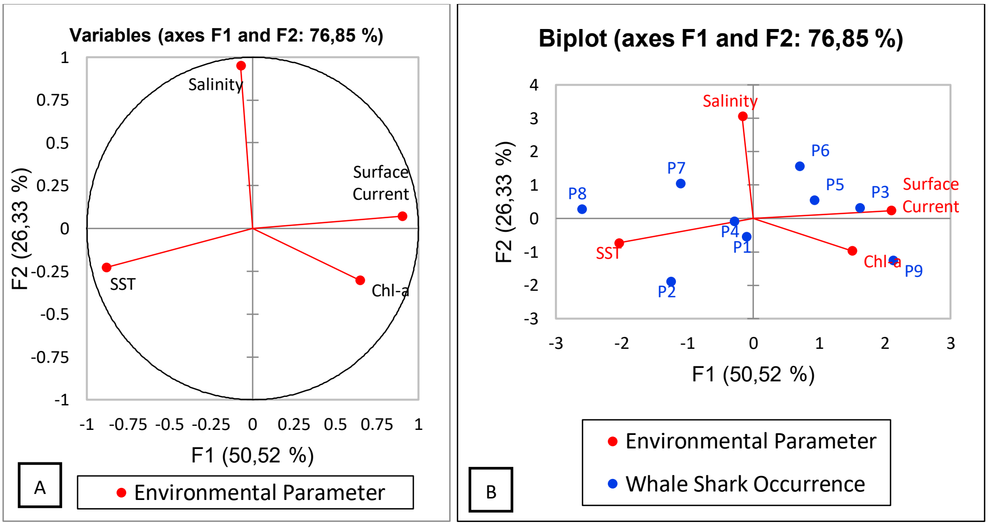

Fig. 4. A. Biplot diagram of the results of PCA analysis showing the ordinalization of several environmental oceanographic parameters in the habitat of whale shark occurrence in Botubarani Coastal Waters; B. Distribution of seasonal whale shark occurrences in June 2022-July 2024 towards environmental oceanographic parameters that characterize the waters of Botubarani Beach.

The distribution of whale shark occurrences at Botubarani Beach showed a clear association with oceanographic variability, particularly surface currents, salinity, and chlorophyll-a concentration. Areas characterized by higher current velocity and elevated chlorophyll-a corresponded to higher observation frequencies, suggesting that both hydrodynamic conditions and primary productivity influence whale shark presence through prey availability. This finding aligns with previous studies that have identified productivity-driven food distribution and current-mediated transport as key drivers of whale shark aggregation in tropical waters. Several studies have shown that environmental factors play an important role in determining the distribution and occurrence of whale sharks. Research has found that sea surface temperature and primary productivity (measured through chlorophyll-a) are the main factors influencing whale shark movement in tropical waters [30]. However, sea surface temperature did not appear to have a strong effect on whale shark occurrence. In 2015, research also showed that the chlorophyll-a concentration correlates with whale shark occurrence at aggregation sites, as high primary productivity attracts zooplankton, their main food source [31]. Research in 2017 further indicated that changes in ocean currents can affect plankton distribution and direct whale shark movement toward areas with more abundant food sources. The results of this analysis suggest that the spatial distribution of whale shark occurrence is likely influenced by a combination of environmental factors, particularly salinity, chlorophyll-a, and surface currents. These factors may influence food availability and the habitat conditions that support the presence of whale sharks.

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Oceanographic parameters did not appear to strongly influence whale shark occurrence. Supporting evidence from several studies indicates that temperature, salinity, and chlorophyll are not the primary factors affecting the presence of whale sharks [5,32]. Whale shark occurrence in Botubarani is influenced by provisioning, seasonal presence of nike fish (*Awaous* sp.), and presence of orcas (*Orcinus orca*), based on field observations and data collection. Nike fish are a type of small pelagic fish found in Gorontalo waters and are locally known as *Duwo*, a term referring to fish that are smaller in size than anchovies [33]. These fish typically migrate in large numbers from coastal waters to the estuary of the Bone River in Gorontalo City, with their appearance occurring periodically at the end of the month just before the new moon.

Provisioning sharks has both direct impacts on the physiology and behavior, and indirect impacts that may affect the ecosystem. Several studies have reported direct effects of provisioning on certain shark species such as the great white shark (*Carcharodon carcharias*), tiger shark (*Galeocerdo cuvier*), and whale shark (*Rhincodon typus*) [34–37] Other studies, however, found no evidence of behaviorally mediated impacts at broader spatial and temporal scales[38]. Potential indirect effects include changes in predator–prey dynamics due to shifts in predator abundance or composition at foraging sites [7].

Various whale shark interaction activities occur in the waters of Botubarani Beach, including diving (both free diving and scuba diving), snorkeling, and direct observation from boats. Each activity involves food provisioning to attract whale sharks that are closer to tourists. The food provided by tourism operators is krill shrimp (*Euphausia* sp.), packaged in plastic bags and sold at Rp. 20,000 per bag. Tourists who want to interact with whale sharks from boats receive one plastic bag of krill. A single boat typically carries four people, consisting of one guide and three tourists. Local fishers move to the center of the interaction zone to “call” whale sharks by knocking on the boat while releasing krill into the water. This practice has been ongoing since whale sharks first appeared at Botubarani in 2016. Whale sharks that appear in the morning generally remain in the Botubarani waters until the afternoon. These tourism activities, while supporting local livelihoods, may influence whale shark behavior and habitat use by promoting food conditioning and altering their natural movement patterns. Understanding both natural (e.g., predator-prey dynamics) and human-driven factors (e.g., feeding and tourism pressure) is essential to support sustainable whale shark management in Botubarani [20]. Whale sharks are still not widely considered the primary prey species in the feeding habits of orcas (*Orcinus orca*), although there are several records from around the world, mostly from remote offshore locations [19]. Predation threats from orcas can drive changes in the behavior and distribution of various marine predators, with defensive responses depending on the balance between mortality risk and prey availability. To date, information regarding the interactions between orcas and whale sharks remains limited, with most accounts originating from local communities and visiting tourists.

4 Conclusion

The occurrence of whale sharks in the waters of Botubarani Beach has been recorded since 2016, with seasonal appearances influenced by the surface temperature, salinity, surface currents, and chlorophyll-a. Anthropogenic pressures, such as tourism and food provisioning, also contribute to changes in whale shark behavior. The whale shark occurrence at Botubarani is shaped by the interplay between oceanographic dynamics and human activities, where favorable environmental conditions coincide with increased tourism intensity. The observed behavioral disturbances, such as abrupt changes, banking, and shuddering during tourist interactions, indicate potential stress responses that may alter natural movement or residency patterns. These findings advance our understanding of whale shark ecology at local aggregation sites by highlighting the dual influence of natural variability and anthropogenic disturbance. Therefore, integrating oceanographic monitoring with responsible tourism management is essential to ensure the long-term sustainability of whale shark occurrences in Botubarani and similar coastal hotspots.

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