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CHECKLIST OF SEA CUCUMBERS SPECIES FROM BILUHU TIMUR WATERS, TOMINI BAY, GORONTALO, INDONESIA, BASED ON THEIR OCCURRENCE ON NEW MOON AND FULL MOON OF LUNAR PHASE

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ABSTRACT

This study presents a comprehensive checklist of sea cucumber species found in Biluhu Timur waters, Tomini Bay, Gorontalo, Indonesia, across the new moon and full moon lunar phases. The survey identified eight species across five genera, including *Actinopyga miliaris*, *A. mauritiana*, *Holothuria scabra*, and *H. leucospilota*. Our finding noted their significant distribution patterns influenced by lunar cycles and different biomes at three stations. The species found were also categorized based on their conservation status, which is the IUCN Red List category. *Actinopyga miliaris* and *A. mauritiana*, both classified as Vulnerable, were more active in the seagrass biome of Station I during the full moon. *H. leucospilota*, classified as Data Deficient, showed notable activity in the coral reef biome of Station III. Environmental parameters such as water temperature, salinity, and pH were measured at each station to understand the conditions influencing these species. This study highlights the importance of lunar phases, biomes, and environmental variables on sea cucumber distribution. The findings underscore the need for conservation efforts that consider these factors to protect species vulnerable to overfishing and habitat degradation. Further research should include genetic analysis and expanded temporal and spatial scales to develop effective conservation strategies and sustainable management practices.

Keywords: Sea cucumbers, Seagrass, Coral reef, Lunar phases, Biodiversity conservation

INTRODUCTION

Sea cucumbers are acknowledged for their significant ecological role within marine ecosystems, acting as deposit feeders by consuming sediment to extract organic matter and microorganisms. This process contributes to nutrient cycling and facilitates the recycling of nutrients in marine environments (Deng et al., 2022). Sea cucumbers are essential ecological engineers that play a crucial part in maintaining the equilibrium of benthic microenvironments, which is vital for the health and productivity of marine ecosystems like coral reefs and seagrass beds (Baker-Médard & Ohl, 2019; Hamamoto et al., 2022). Through their feeding behavior, which includes the bioturbation of sediments, sea cucumbers help decrease microalgal biomass and support nutrient supply in oligotrophic settings (Anderson et al., 2010; Watkins et al., 2023). Furthermore, sea cucumbers are acknowledged for their capacity to improve mineralization and nutrient cycling in coastal sediments, leading to positive effects on sediment biogeochemistry and benthic-pelagic coupling (MacTavish et al., 2012).

Sea cucumbers are essential for ecosystem functioning and possess ecological and bio-medicinal significance. They are recognized for generating bioactive compounds with therapeutic attributes, such as vitamins and triterpenoid glycoside saponins (Rahman et al., 2020). Sea cucumbers are also utilized for their nutritional and medicinal benefits, with the same rich source for both "medicine and food " in aquaculture practices (Hao et al., 2022). Nevertheless, the escalating demand for sea cucumbers has resulted in issues like overharvesting, posing potential detrimental effects on marine ecosystems by disrupting their ecological roles (Ma et al., 2022).

Tomini Bay, the expansive semi-enclosed sea on Sulawesi Island, is part of the Indonesian Seas with a unique area of significant marine biodiversity of the Coral Triangle. The bay waters are known as one of 24 coral systems in the Indo-West Pacific, which is home to the stomatopoda mantis shrimp species *Haptosquilla pulchella* (Barber et al., 2002), and the coral species Heliofungia actiniformis population (a majority Indonesian mushroom coral) which they are an isolated species from the population in the Indo-Malay archipelago (Knittweis et al., 2009). Also, there is a rich biodiversity of leptocephali (Miller et al., 2016) and Nike fish (Olii & Pasisingi, 2023; Sahami & Habibie, 2021). The aquatic environment in this area functions as a refuge for biodiversity and breeding grounds for various species of marine organisms.

The focus location of this research is the waters of Biluhu Timur Village, which is one of the important habitats in Tomini Bay, one of the marine conservation areas in Gorontalo Province, which was determined through Gorontalo Province regional regulation No. 4 of 2018, characterized by its vibrant coral reefs and extensive seagrass beds. These waters, with the geographical isolation of the area, coupled with its dynamic ocean currents (Suniada, 2021), are thought to contribute to its unique biodiversity, making it an ideal location for studying the impact of lunar cycles on marine benthic species.

Sea cucumbers have ecological importance and are an essential component of marine ecosystems; they also contribute significantly to the nutrient cycle and structure of benthic communities. However, research on their population dynamics, especially those related to lunar cycles, is sparse. By focusing on the new moon and full moon phases, this study aims to shed light on how these periods impact sea cucumber activity and visibility, providing insights essential for their conservation and management strategy. The primary goal of this study is to compile a checklist of sea cucumber species observed during the new moon and full moon phases and analyze any patterns in their occurrence.

MATERIALS AND METHODS

The study was conducted in the eastern of the Tihu Atoll waters, the Biluhu Timur's mascot. The location is part of Teluk Tomini in Gorontalo province, Indonesia (Figure 1).

Field Survey and Location Determination

The objective of determining research locations was to select sites representing the diversity of Tomini Bay's ecosystems in Biluhu Timur waters. The initial site surveys were conducted to gather preliminary information about the area, including its general features and the availability and distribution of the research subjects—sea cucumbers. Based on these initial observations, three observation stations were established, representing distinct ecosystems critical for comprehensive ecological assessments:

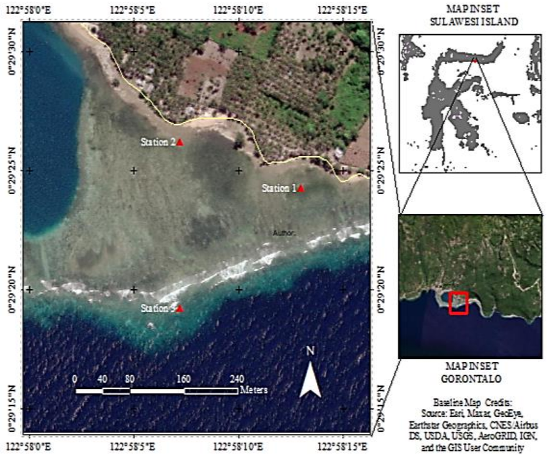

Figure 1. Site location of research

Station I: Encompasses a seagrass ecosystem located at coordinates 0.49008ºN, 122.970293ºE. This station was chosen due to the typical association of seagrass beds with diverse marine life, providing an essential habitat for juvenile sea cucumbers. Station II: Includes a sandy ecosystem, positioned at coordinates 0.49062ºN, 122.96868ºE. Sandy substrates often host different species than seagrass or coral areas, offering insights into the adaptability and distribution of sea cucumber species in such environments. Station III: Covers a coral reef ecosystem, with coordinates 0.488685ºN, 122.96868ºE. Coral reefs are biodiversity hotspots expected to yield diverse sea cucumber populations, potentially affected by biotic and abiotic factors distinct from the other stations. These stations were systematically monitored during new moon and full moon phases to evaluate the influence of lunar cycles on sea cucumber populations.

Species Identification and Determination

Identifying the diversity of sea cucumbers in a given area requires meticulous species identification. Determination keys offer a systematic approach to classifying individuals into their respective taxa. This process involves recognizing and documenting various taxonomic characteristics to categorize them accurately. Identification keys facilitate this by comparing each species' morphological features. As a primary reference, we relied on the "Pedoman Umum Identifikasi dan Pemantauan Populasi Teripang" (DJPRL, 2015). To confirm each species' taxonomy, we used the World Register of Marine Species (WoRMS), accessible at https://www.marinespecies.org/. Additionally, we referred to the IUCN Red List of Threatened Species to determine each species' conservation status via https://www.iucnredlist.org/. In our study, species identification began with a detailed morphological analysis using established marine biology taxonomic keys. Specimens that posed identification challenges during field surveys were carefully collected and transported to the laboratory for further examination.

Data Collection and Analysis

Data Sampling Technique

Data collection was conducted using purposive random sampling, where sampling locations were specifically selected to maximize the observation of nocturnal behaviors. Observations and sampling were conducted using 1x1 m quadrats randomly placed in the chosen locations. These sampling activities were performed exclusively at night, as sea cucumbers are nocturnally active, emerging from their hiding spots to feed or breed after dark. This method ensures that the data captured reflects the natural behaviors and population dynamics under lunar influences, which is crucial for assessing the impact of the lunar cycle on these organisms.

Environmental Parameter Measurements

Water quality parameters were measured on-site to provide contextual environmental data that could influence sea cucumber behaviors. The following procedures were used for each parameter: Temperature: A thermometer was submerged in the water, and the temperature was recorded based on the scale provided. Salinity: Salinity levels were measured using a refractometer. Seawater samples were collected with a pipette, and a drop was placed on the refractometer's slide to determine salinity levels. Current Speed: The speed of water currents was assessed using a current meter attached to a pre-measured rope, alongside a stopwatch to time the flow rate over a known distance. Depth: Depth measurements were taken using a scaled rod or measuring tape extended from the seabed to the surface, ensuring accurate readings of the underwater landscape where sea cucumbers reside. pH: pH levels were measured by dipping litmus paper into the water, with the resulting color compared against a standard pH indicator to determine the acidity or alkalinity of the water.

RESULTS AND DISCUSSION

Species Checklist from Biluhu Timur Coastal Waters

In the research area of Biluhu Timur, a total of eight sea cucumber species from five different genera were identified: Actinopyga (*Actinopyga miliaris* and *Actinopyga mauritiana*), Bohadschia (*Bohadschia similis*), Holothuria (*Holothuria scabra*, *Holothuria leucospilota*, and *Holothuria atra*), Synapta (*Synapta maculata*), and Stichopus (*Stichopus horrens*).

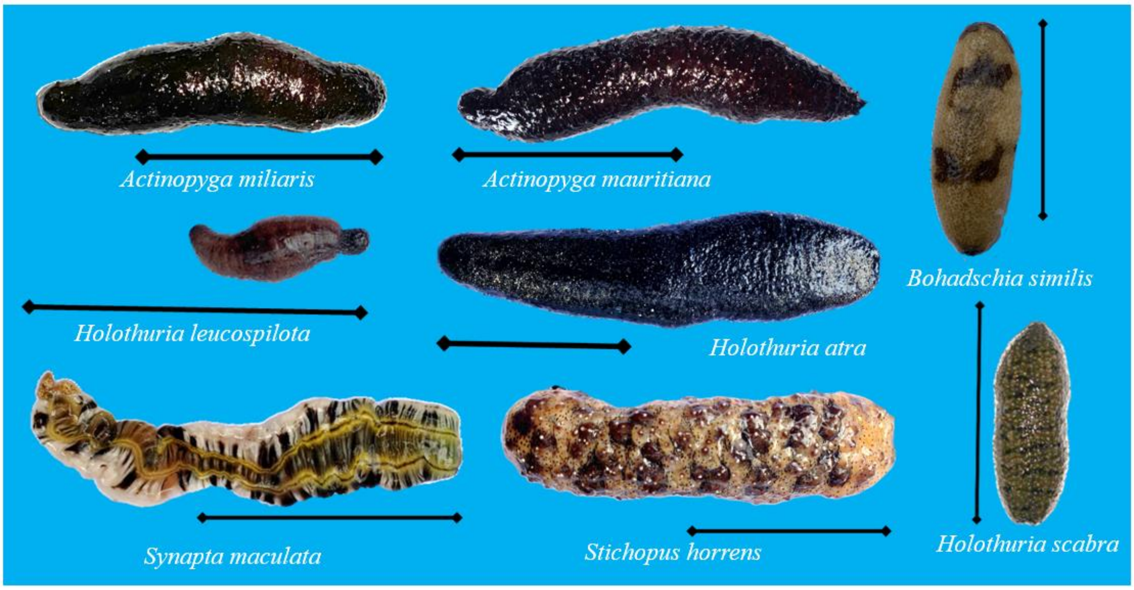

Figure 1. Species list found in Biluhu Timur coastal waters during new-moon and full-moon phase (scale is 10 cm in length)

Species classification of *Actinopyga miliaris*

Morphological Characteristics: *A. miliaris* exhibits a cylindrical body elongated with a convex dorsal side (bivium) and a flat ventral side (trivium). The bivium typically contains mucous and fine sediment, adorned with numerous slender papillae. Its tube feet on the trivium are thick and long, arranged in tight rows. The calcareous disc in the podia measures approximately 700 micrometers in diameter. The mouth, located on the ventral side, is surrounded by 20 robust tentacles, and the anus is encircled by five strong triangular anal teeth. The tentacles feature prominently stalked branches (Basri, 2022). This description is consistent with observations of *A. miliaris* at the research site, where individuals measured approximately 16 cm in length and exhibited similar morphological characteristics to those described in Basri (2022). Taxonomic Classification. Kingdom: Animalia, Phylum: Echinodermata, Class: Holothuroidea, Order: Holothuriida, Family: Holothuriidae, Genus: Actinopyga, Species: *Actinopyga miliaris* (Quoy & Gaimard, 1834)

Species classification of *Actinopyga mauritiana*

Based on observations, *A. mauritiana* individuals have a reddish-black color and elongated body approximately 21 cm long, typically found in seagrass ecosystems with sandy rocky substrates. According to Mustafa et al. (2022), this species generally exhibits a black color and an elongated shape approximately 20 cm long, with a convex dorsal side. *A. mauritiana* is observable in the following representation:

Taxonomic Classification. Kingdom: Animalia, Phylum: Echinodermata, Class: Holothuroidea, Order: Holothuriida, Family: Holothuriidae, Genus: Actinopyga, Species: *Actinopyga mauritiana* (Quoy & Gaimard, 1834).

Species classification of *Bohadschia similis*

Field identification shows that *B. similis* has a white-to-brownish body with a distinctive pattern and dark brown spots. This aligns with the research of Munawwarah (2022) who describes *B. similis* as having a symmetrically patterned dorsal side and a white ventral side, along with dark brown spots and the secretion of a white fluid.

Taxonomic Classification. Kingdom: Animalia, Phylum: Echinodermata, Subphylum: Echinozoa, Class: Holothuroidea, Subclass: Actinopoda, Order: Holothuriida, Family: Holothuriidae, Genus: Bohadschia, Species: *Bohadschia similis* (Semper, 1868)

Species classification of *Holothuria scabra*

Holothuria scabra observed at the research site has an oval-shaped body with a grayish-brown color and distinctive black stripes. The specimens also display a wrinkled texture covered with sand. Setyastuti et al. (2019) describe *H. scabra* as having a plump and fleshy body, grayish-brown color, and distinctive black stripes. They are primarily found in seagrass beds and coral reefs exposed to sandy substrates. Daud (2023) adds that *H. scabra* has an oval-shaped body with gray color and black transverse stripes.

Taxonomic Classification. Kingdom: Animalia, Phylum: Echinodermata, Class: Holothuroidea, Order: Holothuriida, Family: Holothuriidae, Genus: Holothuria, Species: *Holothuria scabra* (Jaeger, 1833).

Species classification of *Holothuria leucospilota*

Holothuria leucospilota is characterized by its blackish-gray body, soft texture, and ability to elongate or shorten. It is often found in sandy substrates. Panggabean et al, (2021) describe *H. leucospilota* as cylindrical, measuring around 9 cm in length and 5 cm in width. Its body is soft and covered in mucus. Its habitat primarily includes seagrass-covered substrates. According to Sihaloho (2022), *H. leucospilota* has an outer surface that's blackish-grey, with smooth and soft skin, and often hides in coral or dead rocks.

Taxonomic Classification. Kingdom: Animalia, Phylum: Echinodermata, Class: Holothuroidea, Order: Holothuriida, Family: Holothuriidae, Genus: Holothuria, Species: *Holothuria (Mertensiothuria) leucospilota* (Brandt, 1835).

Species classification of *Holothuria (Halodeima) atra*

Holothuria (Halodeima) atra has an elongated cylindrical body, approximately 19 cm long and 10 cm wide. Its outer surface is smooth black, and it often buries itself in the sand (Panggabean et al., 2021).

Taxonomic Classification: Kingdom: Animalia, Phylum: Echinodermata, Class: Holothuroidea, Order: Holothuriida, Family: Holothuriidae, Genus: Holothuria, Species: *Holothuria (Halodeima) atra* (Jaeger, 1833)

Species classification of *Synapta maculata*

Synapta maculata was observed during both the New Moon and Full Moon phases in the coral reef ecosystem. It can grow up to 1 meter long in water and about 20 cm on land. Its body is not entirely fleshy but is 80% composed of water, with thin and sticky skin. Hisam et al. (2022) note that *S. maculata* resembles a worm without papillae or tube feet. Its thin body wall is sticky and measures about 30 cm long. The dorsal and ventral sides are gray, encircled with prominent horizontal black stripes, and five lighter brown transverse bands. The anterior end has a mouth surrounded by 15 feather-like tentacles. *S. maculata* is found on delicate sandy substrates covered in seagrass, with a water temperature of 28°C and pH 7.

Taxonomic Classification. Kingdom: Animalia, Phylum: Echinodermata, Subphylum: Echinozoa, Class: Holothuroidea, Subclass: Paractinopoda, Order: Apodida, Family: Synaptidae, Genus: Synapta, Species: *Synapta maculata* (Chamisso & Eysenhardt, 1821).

Species classification of *Stichopus horrens*

Field observations reveal that *S. horrens* has a brown color with black bumps on its body. It is elongated, approximately 20 cm long, with thick, fleshy skin and is commonly found in coral reef ecosystems. According to Munawwarah (2022), *S. horrens* has a long, compact body with thick flesh. The surface alternates between light and dark brown, with irregular stripes and is covered in round bumps.

Taxonomic Classification. Kingdom: Animalia, Phylum: Echinodermata, Class: Holothuroidea, Order: Synallactida, Family: Stichopodidae, Genus: Stichopus, Species: *Stichopus horrens* (Selenka, 1867).

Appearance of Sea Cucumber Species by Lunar Phase and Station

The field surveys conducted in Biluhu Timur, Tomini Bay, documented the occurrences of various sea cucumber species across different lunar phases and ecological stations, each representing distinct biomes. The findings, aligned with the IUCN Red List statuses, are summarized in the table below.

Table 1. Appearance (individuals) and IUCN Red List Status of Sea Cucumber Species Based on Lunar Age Periods at Each Station.

No	Genus	Species	IUCN Red List Status	Station I		Station II		Station III	
				(New Moon)	(Full Moon)	(New Moon)	(Full Moon)	(New Moon)	(Full Moon)
1	Actinopyga	A. miliaris	Vulnerable	3	10	0	0	0	0
		A. mauritiana	Vulnerable	0	1	0	0	0	0
2	Bohadschia	B. similis	Data Deficient	1	2	0	0	0	0
3	Holothuria	H. scabra	Endangered	1	5	0	0	0	0
		H. leucospilota	Least Concern	0	0	141	0	0	0
		H. atra	Least Concern	0	1	0	0	0	1
4	Synapta	S. maculata	Not Evaluated	0	0	0	0	2	6
5	Stichopus	S. horrens	Data Deficient	0	0	0	0	24	18

Table 2. Water Quality Parameters at Each Station During Different Lunar Phases.

No	Parameter	Station I		Station II		Station III	
		(New Moon)	(Full Moon)	(New Moon)	(Full Moon)	(New Moon)	(Full Moon)
1	Water Temperature (°C)	27	28	27.6	28.5	28	27.6
2	Depth (cm)	36.8	43	1.2	36	220	230
3	Salinity (‰)	40	31	40	38.6	40	29
4	pH	8.5	8	7.8	8.8	7	7.81
5	Current (m/s)	0.02	0.07	-	0.03	0.04	0.09

Key observations include the significant appearance of *Holothuria leucospilota* at Station II during the new moon with 141 individuals and notable appearances of *Stichopus Horrens* at Station III during the full moon with 18 individuals. Table 2 details the environmental parameters measured at each station during different lunar phases, providing insight into the conditions under which the various species were observed. Environmental observations highlight varying conditions across stations, such as a lower salinity at Station I during the full moon and higher water depths at Station III, which could potentially influence species distribution and behavior patterns observed.

DISCUSSION

Synthesis of Findings

The study reveals that *A. miliaris* and *A. mauritiana*, both classified as Vulnerable, display specific ecological behaviors tied to their biome preferences and reproductive strategies. These species, known for their group spawning behavior and specific dietary preferences (Weese & Duda, 2019; Yunita et al., 2022), are influenced by environmental factors such as water temperature and salinity, which align with their occurrence patterns observed during the full moon at Station I.

Holothuria scabra, an endangered species, and *H. atra*, classified as least Concerned, demonstrate habitat preferences that align with their physiological and reproductive needs. For *H. scabra*, the interaction with seagrass has been shown to enhance its growth rate (Arnull et al., 2021), which supports its occurrence in similar biomes in Biluhu Timur. However, this was not directly observed in our study. The significant appearance of *H. leucospilota* at Station II during the new moon aligns with studies indicating that lunar cycles significantly influence the reproductive cycles of sea cucumbers (Purcell et al., 2011).

The appearance of sea cucumber species in Biluhu Timur Village, Tomini Bay, is influenced by various water quality parameters, as shown in Tables 1 and 2. Water temperature, which remained stable between 27°C and 28.5°C across all stations, falls within the tolerance range for sea cucumbers, with *H. leucospilota* thriving at Station II during the New Moon when the temperature was 27.6°C. Water depth also played a crucial role, with Station II's shallow depth of 1.2 cm during the New Moon favoring the high concentration of *H. leucospilota*. In comparison, the greater depths of 220-230 cm at Station III supported species like *S. maculata* and *S. horrens*. Salinity fluctuations, particularly the drop from 40‰ to 31‰ at Station I during the Full Moon, might have disrupted species' habitat preferences, such as *A. miliaris* and *H. scabra*, influencing their movement. The pH values, ranging from 7 to 8.8, were generally within acceptable limits, though the increase to 8.8 at Station II during the Full Moon could have deterred *H. leucospilota*. Additionally, the higher current speed at Station III (0.09 m/s during the Full Moon) created a more dynamic environment, beneficial for species like *S. horrens* that prefer enhanced nutrient availability and oxygenation from the higher currents.

Synapta maculata and *S. horrens* were found exclusively at Station III, likely due to the complex habitat of the coral reef ecosystem, which offers numerous hiding spots and abundant food sources. According to Tanita & Yamada (2019), the diverse physical structure of coral reefs provides a variety of micro-habitats that meet the specific needs of sea cucumbers such as *S. maculata*. This preference for certain micro-habitats in coral reef ecosystems may be related to the complexity of lagoonal-scale topography and sediment/biota conditions that support the coexistence of various sea cucumber species. Similarly, *S. horrens*, like other *Stichopodids*, is a deposit feeder that inhabits backreefs, inner lagoons, bays, and reef slopes, and is known to be nocturnally active, with adults hiding in reef crevices or under rocks during the day as shown by Palomar-Abesamis et al. (2017). Their results showed that juveniles of *S. horrens* are more abundant in seagrass areas and the transition zones between seagrass and rubble-dominated reef flats, further emphasizing the importance of habitat complexity and nutrient availability in influencing the distribution patterns of sea cucumbers.

Conservation Insights

Sea cucumbers' varying abundance and visibility during different lunar phases directly affect conservation strategies. The knowledge gained can aid in developing targeted conservation practices, such as establishing no-take zones during specific lunar phases when sea cucumbers are most active and vulnerable. Additionally, understanding these species' habitat preferences and activity peaks supports the need for habitat protection measures, especially in regions like Station II and III, where significant occurrences were recorded.

This study also highlights the importance of maintaining ecological integrity in Tomini Bay. Sea cucumbers play a vital role in nutrient cycling and are bioindicators of marine health, so their protection is crucial for sustaining the area's marine biodiversity. Our findings can inform local conservation policies and contribute to the ongoing efforts by the Indonesian government and non-governmental organizations to protect marine life.

Ecological and Conservation Implications

Understanding these species' ecological roles and behavioral ecology is crucial for developing targeted conservation strategies. For instance, *A. mauritiana's* high commercial value and specific habitat needs highlight the importance of protecting seagrass and sandy lagoon biomes (Arfani et al., 2021; Setyastuti et al., 2018).

The findings from this study suggest that environmental management and conservation efforts should be finely tuned to each species' specific ecological and reproductive needs. For example, protecting areas where vulnerable species like *A. miliaris* and *A. mauritiana* are found during their peak reproductive periods could significantly impact their population stability.

Limitations and Further Research

While the current study provides foundational insights into the distribution and environmental preferences of sea cucumbers in Biluhu Timur, Tomini Bay, it faces certain limitations that must be addressed in future research. One of the primary constraints is the study's limited temporal and spatial scope, confined to specific lunar phases and three predefined stations. To enhance the robustness of the findings, future studies should encompass a broader temporal range, covering entire lunar cycles to capture more comprehensive data on the behavioral patterns of sea cucumbers. Expanding the spatial scale to include more diverse regional habitats could uncover additional nuances in sea cucumber behavior and ecology.

Including additional environmental variables such as water temperature, salinity, and current strength spatially and temporarily could significantly refine our understanding of how these factors correlate with sea cucumber activity and ecological preferences. This approach would allow for a more detailed analysis of the environmental conditions that influence sea cucumber distribution and behavior, particularly their reproductive cycles, which are sensitive to such factors.

Further research should delve into the genetic diversity of sea cucumber populations to assess their resilience to environmental changes and anthropogenic pressures. Understanding the genetic basis of adaptability and resilience in sea cucumbers could aid in identifying populations at risk and formulating effective conservation strategies. Additionally, conducting detailed biochemical analyses could uncover potential nutraceutical or pharmacological uses of sea cucumbers, which have been noted for their bioactive properties. Such studies are essential for conservation and exploring sustainable economic opportunities that benefit local communities while preserving marine biodiversity. Further research should also examine the genetic diversity of these populations to assess their resilience to environmental changes. Given the crucial ecological role of sea cucumbers and their vulnerability to overfishing and habitat destruction, extended studies are vital for developing more effective conservation strategies and sustainable management practices in marine ecosystems.

CONCLUSION

This study presented a detailed checklist of sea cucumber species found in Biluhu Timur waters, Tomini Bay, Gorontalo, Indonesia, across the new moon and full moon lunar phases. Identifying key species, including *A. miliaris*, *A. mauritiana*, *H. scabra*, and *H. leucospilota*, highlighted significant differences in distribution patterns across various stations and lunar phases. For instance, *H. leucospilota* exhibited a striking concentration in the sandy substrate of Station II during the new moon, while *A. miliaris* and *A. mauritiana* were more active during the full moon at Station I.

The study's findings emphasize the influence of lunar phases and environmental parameters, such as salinity and pH, on the ecological behavior of these species. The observations underscore the need for conservation efforts tailored to these sea cucumbers' reproductive cycles and habitat preferences, particularly for those listed as vulnerable or endangered.

While the research provides valuable ecological insights, it also has limitations that future studies should address. Expanding the temporal and spatial scope to encompass more comprehensive data across all lunar phases and stations will uncover nuanced behavioral patterns. Moreover, correlating environmental variables like water temperature, salinity, and currents with sea cucumber activity can refine our understanding of their ecological preferences. Exploring the genetic diversity of these populations will also help assess their resilience to environmental changes and inform conservation strategies.

These extended studies will be critical for developing effective conservation strategies and sustainable management practices that acknowledge the ecological roles of sea cucumbers and their economic potential. Addressing these gaps will contribute to the sustainable use and protection of sea cucumber populations, ensuring the health and stability of the marine ecosystems they help support.

ACKNOWLEDGMENT

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