EAM
Environmental and Materials
EAM 1(1): 41–48
ISSN 3025-0277

Diversity analysis of moray eel (*muraenidae*) on artificial reef structure in mengiat beach, Nusa Dua, Bali

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Received Date: May 11, 2023 Revised Date: June 22, 2023 Accepted Date: June 23, 2023

Cite This Article:
Wilbert, N., & Nugrahapraja, H. (2023). Diversity Analysis Of Moray Eel (Muraenidae) On Artificial Reef Structure In Mengiat Beach, Nusa Dua, Bali. *Environmental and Materials, 1*(1), 41-48. https://doi.org/10.61511/eam.v1i1.2023.62

Abstract
Optimal coral growth has a positive impact on increasing biodiversity. This can be observed through the increase in the number of marine species as the transplanted coral reefs age. One natural indicator in coastal ecosystems is the presence of moray eels. Within the coral reef ecosystem, the diversity of moray eels as natural predators belonging to the category of reef fish can serve as an indication of a healthy and balanced ecosystem. The method used in this research is visual counting or visual observation of several species of marine eels on three different major installed reef star media, as part of coral reef restoration efforts. The data collection locations include three points of reef star media installation: BTN, Coral Garden, and Cluster 5. The water conditions in these locations, such as salinity, temperature, pH, and conductivity, indicate the adequate quality to support coral reef restoration efforts. In this study, five species of marine eels frequently encountered in the three data collection locations identified as: *Echidna nebulosa, Gymnothorax thyrsoideus, Gymnothorax fimbriatus, Gymnothorax pictus,* and *Gymnothorax richardsonii*. The highest abundance and diversity were found in Coral Garden, followed by Cluster 5, with BTN being the lowest.
Keywords: coral reef; moray eel; restoration

1. Introduction

Republic of Indonesia is an archipelagic state having an immensely large waters area. In these humongous waters area, there are many natural resources that could be utilized. One of the valuable marine resources is coral reefs. Aside from its significant tourism potential, coral reef ecosystems play a crucial role in enhancing marine biodiversity, and indirectly contributing to the well-being of communities. In Indonesia, the estimated extent of coral reefs is approximately 51,000 km^2, covering 51% of the total coral reef area in Southeast Asia and 18% worldwide (Burke et al., 2002, Marie et al., 2007, Luthfi et al., 2016)

Coral reefs are tropical coastal ecosystems formed by the deposition of calcium carbonate produced by reef-building coral organisms (Cnidaria) in symbiosis with zooxanthellae algae and other organisms. Coral reef ecosystems are dynamic, characterized by high biodiversity and productivity. They serve as habitats for marine life and support biodiversity, while also providing physical protection against coastal erosion (Suryanti et al., 2011, Salsabiela et al., 2014).

Aside from its benefits, coral reefs are highly vulnerable to damage caused by several factors, including human activities such as coral mining for construction materials (Kholish, 2013; Sunarto, 2006), destructive fishing practices (Sunarto, 2006), as well as irresponsible tourism and development (Yusnita, 2014). Furthermore, climate change-related factors such as increasing sea temperatures leading to coral bleaching (Pasanea, 2013), changes in pH and salinity, natural disasters, and predation also pose threats to coral reef ecosystems. Considering the multitude of factors that can cause coral damage, numerous efforts are currently underway to preserve coral reefs, including conservation and restoration (Goreau et al, 2005)

Conservation, restoration, and rehabilitation of coral reefs typically involve coral transplantation. This transplantation plays a crucial role in accelerating the regeneration of damaged coral reefs or establishing new communities in specific areas. One commonly used transplantation method is the Mars Assisted Coral Reef Rehabilitation System (MARRS). The MARRS method utilizes iron-based structures coated with sand as substrates for coral transplantation. The structure and form of MARRS reef stars can be adjusted to match the landscape of the coral planting site. This method is chosen because it can mitigate the negative impacts of coral planting failures and serve as the foundation for the formation of a new ecosystem that supports the biodiversity increase in coral reef ecosystems (Mars, 2017).

Moray eels are commonly found in coastal ecosystems, including coral reefs. Categorized as the family of Muraenidae, moray eels have distinct physical characteristics such as a long, slender body and often vibrant colors. They inhabit crevices and caves within coral reefs, stealthily stalking their prey. Moray eels are important predators in the food chain of coral reef ecosystems and play a vital role in maintaining the ecosystem's balance.

Mengiat beach, located in Nusa Dua, Bali, is one of the sites with artificial coral reef structures. These structures were created as part of efforts to restore the damaged coral reef ecosystems caused by human disturbances. The artificial coral reef structures in Mengiat beach have provided new habitat opportunities for various species, including moray eels, allowing them to expand their range. In coral reef restoration efforts, the diversity of fish species over the years can indicate the success of restoration initiatives in a specific area. The emergence of various new moray eel species can signify that the restored coral ecosystem is progressing towards stability and balance.

In this study, survey locations were conducted to identify moray eel species present in artificial coral reef structures. Data on species diversity, abundance, and distribution patterns were collected and analyzed. The results of this research are expected to provide a better understanding of moray eel populations in artificial coral reef structures and their contribution to biodiversity in Mengiat beach, Nusa Dua, Bali.

This study holds significant importance in the context of coral reef conservation and ecosystem management. Information on moray eel diversity will assist in taking the informed decisions regarding appropriate conservation measures to protect moray eel populations and the overall coral reef ecosystem. Thus, this research will contribute valuable insights for the biodiversity of Bali's waters and the importance of protecting moray eels and coral reef ecosystems.

2. Methods

2.1. Time and Location of the Research

This research was conducted at Mengiat Beach, Nusa Dua, Bali, with the assistance of the Nusa Dua Reef Foundation Bali located in the Nusa Dua Tourist Area BTDC, Jl. Nusa Dua, Benoa, South Kuta District, Badung Regency, Bali, 80361. The research was carried out from June 22, 2022, to July 28, 2022. The study began with the selection of data collection sites, which were three artificial coral reef installation locations, namely BTN, Coral Garden (CG), and Cluster 5. Figure 1 shows the research locations conducted at Mengiat Beach.

Figure 1. Data collection locations: (a) BTN, (b) CG, and (c) Cluster 5

2.2. Equipment and Materials

To determine the locations accurately, a GPS device was used, which facilitated to pinpointing the exact positions of the three data collection points. Subsequently, comprehensive observations were conducted on the condition of the coral planted on the reef star structures at these three locations. During the observation process, a GoPro camera was used to record the conditions at each point.

2.3. Data Collection

To measure and analyze the diversity of moray eels, the abundance of moray eels at each point was calculated by using the visual count method. Subsequently, each individual moray eel found was recorded using a slate and pencil. Coral reef restoration was conducted using the MARRS method, which involved creating reef star-shaped media structures to anchor coral fragments and coral larvae for natural recruitment (Figure 2). After documenting the findings of moray eels using a camera, an analysis regarding the relationship between coral reef restoration success and moray eel diversity was conducted. Data collection, including species recording and photography, was performed three times each week at the low tide period.

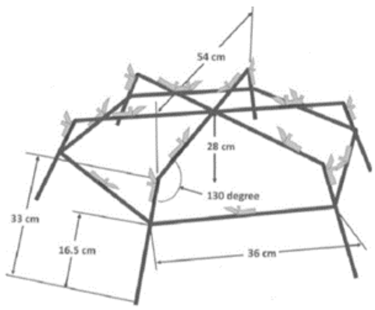

Figure 2. Placement locations of coral fragments on the reef star structure.
Source: Williams, 2018

3. Results and Discussion

In determining the data collection locations, a search was conducted for the largest MARRS reef star installation sites that encompassed a relevant range of coral transplantation ages. After discussions with the Nusa Dua Reef Foundation (NDRF), three of the largest sites commonly used for coral transplantation and maintenance by NDRF were identified. These three locations were BTN, CG, and cluster 5. Based on the observations made at these three locations, it was found that there were approximately 250 reef star media with one iron structure at BTN, 84 at CG with the best coral condition, and 300 reef star media at cluster 5. The transplanted corals at these three location points showed significant age differences. The corals at CG were approximately 6 years old, thus exhibiting a relatively large size compared to the corals at BTN and cluster 5, which were 20 months to 3 years and 20 months old, respectively.

Based on the observations, an analysis was conducted to determine whether the three locations were suitable for coral transplantation and to assess the types of corals that were suitable for transplantation. From these observations, it was found that Mengiat beach has a depth of approximately 1-2 meters during low tide and 3-6 meters during high tide. Based on these observations, it was determined that the three locations were suitable for coral transplantation.

From Figure 3(a-c), the coral growth conditions in the three locations can be observed. The success of the restoration efforts can be seen in the coral growth at the CG location, which indicates that Coral Garden has a wide coverage of coral reefs with various coral species. At the BTN installation site, the transplanted corals showed good development, although the coral coverage was not as extensive as in Coral Garden. Many reef stars were used for coral transplantation at BTN, but most of the corals also grew well on the existing rocks in the vicinity. At the Cluster 5 installation site, the coral coverage has not reached the same level of success as Coral Garden and BTN. There were still many empty structures that have not been used for coral transplantation, which have become substrates for the growth of macroalgae (Kadi, A., 2006). Nevertheless, some locations have shown good coral growth and the ability to survive in the environment. The dominant coral species in the three reef star installation locations are Acropora sp.

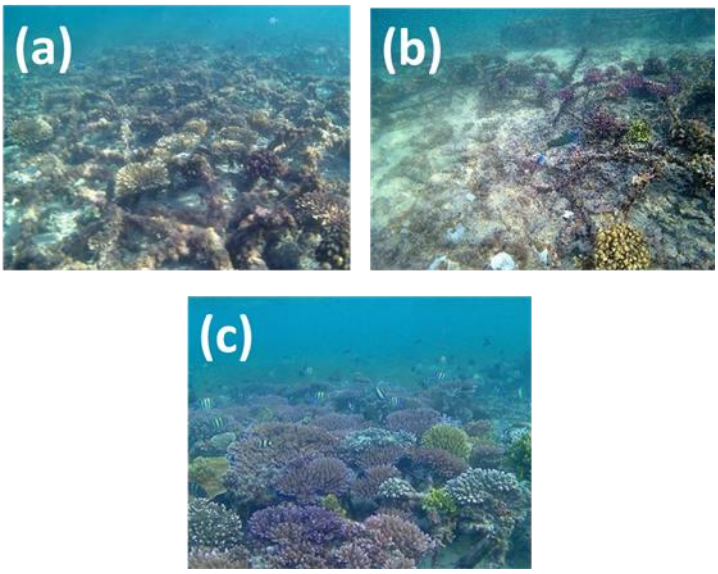

Figure 3. (a) Appearance of Reef Star Media at Coral Garden; (b) BTN; and (c) Cluster 5 (Source: Personal Documentation, 2022.)

The moray eel is one of the common marine organisms found in coral reef ecosystems. Moray eels are generally found in tropical and subtropical waters, with the majority of species inhabiting saltwater environments and a small portion living in freshwater ecosystems. Despite their snake-like appearance, moray eels are classified as fish. They have elongated bodies and fins with very small scales. These eels are typically slimy and exhibit bright colors as a camouflage mechanism among the coral reefs. Their heads resemble those of eels, with a pair of eyes, olfactory openings, and a mouth filled with teeth. Due to their poor eyesight, moray eels rely on their acute sense of smell to locate prey (Randall, 2007). One unique feature of moray eels is that they possess two different sets of jaws to capture their prey. Since moray eels rely on their sense of smell to locate food, they often remain motionless in crevices among rocks/coral reefs, with only their heads visible, waiting for prey to pass by before striking. This hunting style gives them an advantage, as their dual jaws effectively capture and transport prey that has been bitten into their throats. The Indo-Pacific region, including Indonesia, is a center of diversity for the Muraenidae family, with nearly 150 species identified (Briggs, 1999, Böhlke et al., 2002, McCosker et al., 2007).

Moray eels are commonly used as indicators of coral reef ecosystem stability. Therefore, in this study, observations of moray eel diversity were conducted. The observations were carried out at three locations where media reef stars were installed as coral reef restoration efforts. We documented several species that we encountered at these three locations in Figure 4.

The first observed species is the snowflake moray (*Echidna nebulosa*). Snowflake morays are commonly found in warm-water coral reef ecosystems throughout the Indo-Pacific region. These marine eels often roam around coral reefs and rocky substrates. *Echidna nebulosa* has an elongated body with a white color and black spots, as seen in the Figure 4a. The uniqueness of this species lies in its blunt teeth, which are specialized for feeding on various crustaceans (Randall, 2010). Moray eels can reach the lengths of up to 100 cm, although they are commonly found around 50 cm in length.

Additionally, there is another species known as the white-eyed moray or *Gymnothorax thyrsoideus*, displayed in Figure 4(b). White-eyed morays, also known as grey face morays,

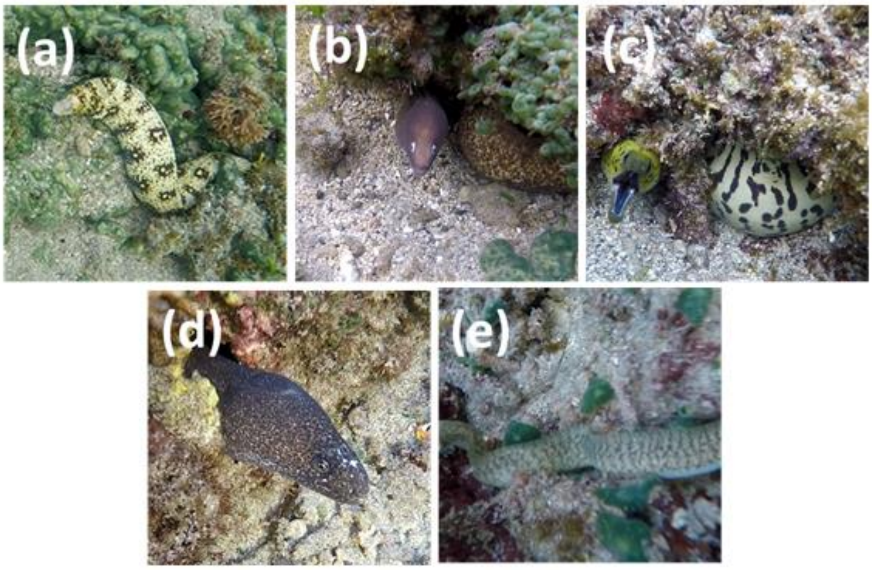

Figure 4. (a) Snowflake moray (*Echidna nebulosa*); (b) White-eyed moray (*Gymnothorax thyrsoideus*); (c) Fimbriated moray (*Gymnothorax fimbriatus*); (d) Paintspotted moray (*Gymnothorax pictus*); (e) Richardson's moray (*Gymnothorax richardsoni*)

are distributed in warm waters across much of the Indo-Pacific region. These morays tend to inhabit shallow, turbid waters such as lagoons and coral reef ecosystems with crevices as sheltering spots (Allen et al., 2012). They have a dark brown coloration along their body and can grow up to 66 cm in length. White-eyed morays are active during the night, searching for small fish and crustaceans near the seabed for their food source.

There are several other moray species that were also observed, one of which is the fimbriated moray (*Gymnothorax fimbriatus*), commonly found in tropical waters across the Indo-Pacific region (Figure 4c). Fimbriated morays tend to inhabit the slightly turbid waters and coral reef ecosystems, as they provide sufficient shelter and food sources. These morays have a relatively large body size and can grow up to 80 cm in length. Their body is light brownish-green with black spots along the body. The head of this moray is yellowish-green in color and has a distinctive narrow and elongated jaw (Allen et al., 2012). The diet of fimbriated morays consists of small fish and abundant crustaceans found in coral reef ecosystems.

Additionally, there is the paint spotted moray, which is typically found only in warm tropical waters. This moray species usually inhabits reef flats with crevices. It has a larger body size compared to other moray species found in shallow waters, reaching a length of up to 140 cm (Smith et al., 2019). The body of the paint spotted moray is bluish-purple with white spots along its body, as seen in Figure 4(d). During the initial growth stage, the body of this moray lacks spots, but they develop as the moray ages. The diet of the paint spotted moray generally consists of reef fish and crustaceans. It is important to note that this moray is venomous and should not be consumed.

The last observed moray species is Richardson's moray, which is typically found in tropical waters throughout the Indo-Pacific region. This moray species relies on shallow marine coral reef ecosystems with depths ranging from 1 to 12 meters, providing protection from predators. Richardson's moray is relatively small compared to other moray species, with a maximum length of about 30 cm (Figure 4e). Its diet consists of small crustaceans found on the seabed. The body of this moray is greenish with black lines along its body. It exhibits swift movements and is capable of hiding in very small crevices.

During the data collection process, there were several other species of moray eels observed, but unfortunately, they could not be fully documented. Other species of moray eels are generally rarely encountered, making it difficult to identify them. Additionally, the observation of moray eel diversity was limited by the available methods and time of observation.

Moray eels are nocturnal creatures and typically active after sunset. The author conducted the data collection on moray eel diversity in the late afternoon to evening, from approximately 4:00 PM to 6:00 PM local time. However, data collection was limited due to the risk of high tide and increasingly unfavorable conditions caused by currents and insufficient lighting. Therefore, the diversity data could only be obtained for certain frequently encountered species. The abundance data of observed moray eels during three data collection sessions in weeks with low tide are summarized in Table 1.

Table 1. Species and number of individuals observed at the three data collection locations

Location	Species Name	Juvenile	Adult
BTN	*Gymnothorax pictus*		I
	Gymnothorax thyrsoideus		II
	Echidna nebulosi		I
Coral Garden	*Gymnothorax richardsonii*	II	I
	Echidna nebulosi		II
	Gymnothorax fimbriatus		I
	Gymnothorax thyrsoideus		II
Cluster 5	*Gymnothorax thyrsoideus*		I
	Gymnothorax richardsonii		II
	Gymnothorax fimbriatus		I
	Echidna nebulosi	I	I

From the Table 1, it can be seen that the highest number of moray eel species and individuals is found at Coral Garden. This may be due to better coral coverage at Coral Garden compared to the other locations. Additionally, the transplanted corals at Coral Garden are older, making them more stable in supporting the ecosystem. In addition to moray eels, the abundance and diversity of reef fish are also higher at Coral Garden compared to other locations.

Although the level of coral coverage and age of transplanted corals are not as good as Coral Garden, Cluster 5 also exhibits high levels of diversity, although the number of individuals is not as high as at Coral Garden. In Cluster 5, there are many scattered debris or rubble in various places. These debris provide ideal hiding places for moray eels to wait and hide during the day (Randall, 2010).

At the data collection location in BTN, the diversity and abundance of moray eels are not as high as in other locations. However, some species, such as *Gymnothorax pictus*, which are relatively large, are only found in BTN. This is due to the presence of natural rocks in BTN that are covered with coral. These rocks have larger crevices, allowing the presence of moray eels with relatively larger bodies.

Based on the observations of moray eel species diversity on artificial coral reefs, it can be concluded that there is variation in the observed species of moray eels at the observation sites. Coral Garden exhibits the highest level of diversity, followed by Cluster 5 and BTN. This diversity is influenced by factors such as coral coverage, coral age, and the availability of shelters such as debris or rubble.

Furthermore, it is important to note that moray eels play a significant role in coral reef ecosystems. Their presence serves not only as an indicator of coral reef restoration success but also signifies the ecosystem stability. Moray eels also act as natural indicators of ciguatera contamination in the waters. Ciguatera Fish Poisoning is a toxin-induced illness caused by consuming reef fish contaminated with ciguatoxin (CTX). As apex predators in coral reef ecosystems, moray eels can accumulate significant amounts of CTX if the waters are polluted. Therefore, analyzing CTX contamination in the flesh and organs of moray eels can provide information about the levels of ciguatera contamination in the waters.

Thus, studying the diversity of moray eels in artificial coral reefs not only provides insights into the biodiversity of the ecosystem but also significantly contributes for the monitoring of water cleanliness and the health of coral reef ecosystems.

4. Conclusions

The following are the conclusions drawn from the conducted research:

1. The data collection sites involved three installation points of reef star media with different ages, namely BTN (S 08° 48,798' E 115° 13,876'), Coral Garden (S 08° 48,828' E 115° 13.854'), and Cluster 5 (S 08° 48,868' E 115° 13,804'). Based on parameters such as salinity, temperature, pH, and conductivity, the water conditions at all three locations were favorable enough to support coral reef restoration efforts.
2. The transplanted coral reefs at the data collection sites were still in good condition, although there were some issues that could disrupt restoration efforts, such as irresponsible anthropogenic activities, a significant amount of waste presence, and algal blooming events due to the relatively shallow rehabilitation location. The dominant coral genus capable of adapting and thriving in all three locations was Acropora.
3. Five frequently encountered moray eel species were identified at the three data collection sites: *Echidna nebulosa, Gymnothorax thyrsoideus, Gymnothorax fimbriatus, Gymnothorax pictus,* and *Gymnothorax richardsonii*. The highest abundance and diversity levels were observed in Coral Garden, followed by Cluster 5, with BTN being the least diverse.

Acknowledgement

The preparation of this research would not have been possible without the assistance, guidance, and support of many individuals involved during the research. Therefore, I would like to express my deepest gratitude to the following: The Head and Director of the Nusa Dua Reef Foundation, Ms. Pariama M.D. Hutasoit, for providing me with the opportunity to undertake the research at NDRF. Putu Natalia Sarasvati, who served as my supervisor throughout the research at NDRF. Ni Putu Laras Berliana Cahayani, who not only acted as the field administration staff but also provided guidance during the research. I Made Takuma Wira Putra, who served as my field supervisor during the research. Mr. Husna Nugrahapraja, S.Si., M.Si., Ph.D., as the coordinator of the research program. The evaluating faculty members who reviewed and checked this report.

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