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The Impacts of Pieh Marine Protected Area on Reef Fish Resources In Its Adjacent Areas

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ABSTRACT

Reef fish have a high economic value. Excessive fishing causes degradation of reef fish resources, as has occurred in the West Sumatera waters. Marine protected areas (MPA) offer one of the better management strategies in support of the restoration of the overexploited fish resources by protecting fish habitat and limiting exploitation. This study aims to analyze the impacts of the establishment of MPA on reef fish resources in its adjacent areas. The research was carried out in Pieh MPA and its adjacent areas located in the West Sumatra waters. Fishing experiments were conducted inside the core zone of the MPA and the catch was compared to similar experiments outside MPA. The result showed that the catch per unit effort (CPUE) of reef fishes in the core zone of MPA was 2.47 times higher than that of in the outside of MPA. However, the size composition was not significantly different between those two areas, except for *Lutjanus russellii*, which shows that the maximum length inside MPA was about 2.5 times higher. The length and weight of Epinephelus areolatus were analyzed to determine the biological condition of the grouper caught in both areas. The length-weight analysis shows that 86.67% of *E. areolatus* were matured. Nevertheless, the length of maturity in the MPA is smaller, indicating there is the impact of epreviously fishing pressure on *E. areolatus*. Research results showed that the MPA is double in fish abundance.

1. Introduction

Fish resources are under significant pressure from fishing efforts that cause fish stock to be fully exploited or even overfished (Pauly *et al.* 1998). According to the Ministerial decree of the Indonesian Ministry of Marine Affairs and Fisheries No.19/2022 (MMAF 2022), reef fishes around West Sumatera waters are in an overfished status. Development of marine protected areas (MPAs) is a management strategy that can withstand anthropogenic and environmental changes (Weigel *et al.* 2014). A review by Lester *et al.* (2009) found that MPAs have significant effects on biomass and density of the fish species, yielding 446% and 166% average increases, with 194% and 61% median increases, respectively. Another role of MPAs is as suppliers of recruits for surrounding water through spillover mechanisms (Di Lorenzo *et al.* 2016). Continued spillover from MPAs is expected to maintain the fish stock sustainability and diversity (Stobart *et al.* 2009; Scibberas *et al.* 2013).

The existence of MPAs also provides an opportunity for ecosystems to recover and develop that leads to a positive impact on improving ecosystem conditions (Millazo *et al.* 2002; Mumby and Harborne 2010). Furthermore, based on Goni *et al.* (2010), MPAs will have an impact on the fisheries aspect if the fish mortality rate decreases and the level of compliance with the prohibition on fishing activities is effective or within a certain time span the area can recover. A good MPA will contribute to improve fisheries aspects through the abundance of fish resources and the export of fish eggs and larvae to the surrounding waters.

Conservation emergency has recently been discussed as part of a broader discourse on global environmental change, resilience of social-ecological

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systems, and common pool resources (Berjed and Armitage 2016; Ceccarelli *et al.* 2022). The effectiveness of conservation areas can be evaluated through the impacts resulting from the conditions of fish resources. According to Lester *et al.* (2009), the benefits and impacts of MPAs on fisheries can be measured using four indicators: biomass, density, size, and species richness. Successful MPAs are expected to support fish resources in adjacent areas (Di Lorenzo *et al.* 2016; Stobart *et al.* 2009). Comparing the indicators of MPA effectiveness between inside and outside the MPAs can show the impacts of MPAs development. For example, Stobart *et al.* (2009) found that fish abundance in the protected area was 1.5 times higher and fish biomass was 1.9 times higher compared to its adjacent area.

This study was conducted to evaluate the effectiveness of Pieh MPA, a national-level MPA located in the West Sumatra waters, about 39 km from Sumatra mainland. Pieh MPA has been developed since 2000 based on the Minister of Forestry and Plantation decree number 70/KPTS-II/2000 (MFP 2000) and has been well-managed by the Ministry for Marine Affairs and Fisheries since 2009 based on the Minister for Marine Affairs and Fisheries decree number KEPMEN No. 70/2009 (MMAF 2009). On the other hand, the West Sumatra waters are an excessive fishing area, with the high fishing pressures leading to over-exploited condition of some groups of fish species, such as reef fishes (MMAF 2022). This study aims to analyze the impacts of Pieh MPA existence on reef fish resources in MPA adjacent areas.

2. Materials and Methods

2.1. Description of Study Sites

The Marine protected area of Pieh Islands (Pieh MPA) is one of the MPAs managed by national authority located in West Sumatra Province, covering 39,900 hectares, and consisting of five small islands located about 22 miles in front of Sumatra mainland, called Pieh Island, Pandan Island, Toran Island, Air Island, and Bando Island (Figure 1). The core zones exist in each island, located from the coastline to about 300–500 meters to offshores. The main ecosystems in this area are fringing reef, deep reef,

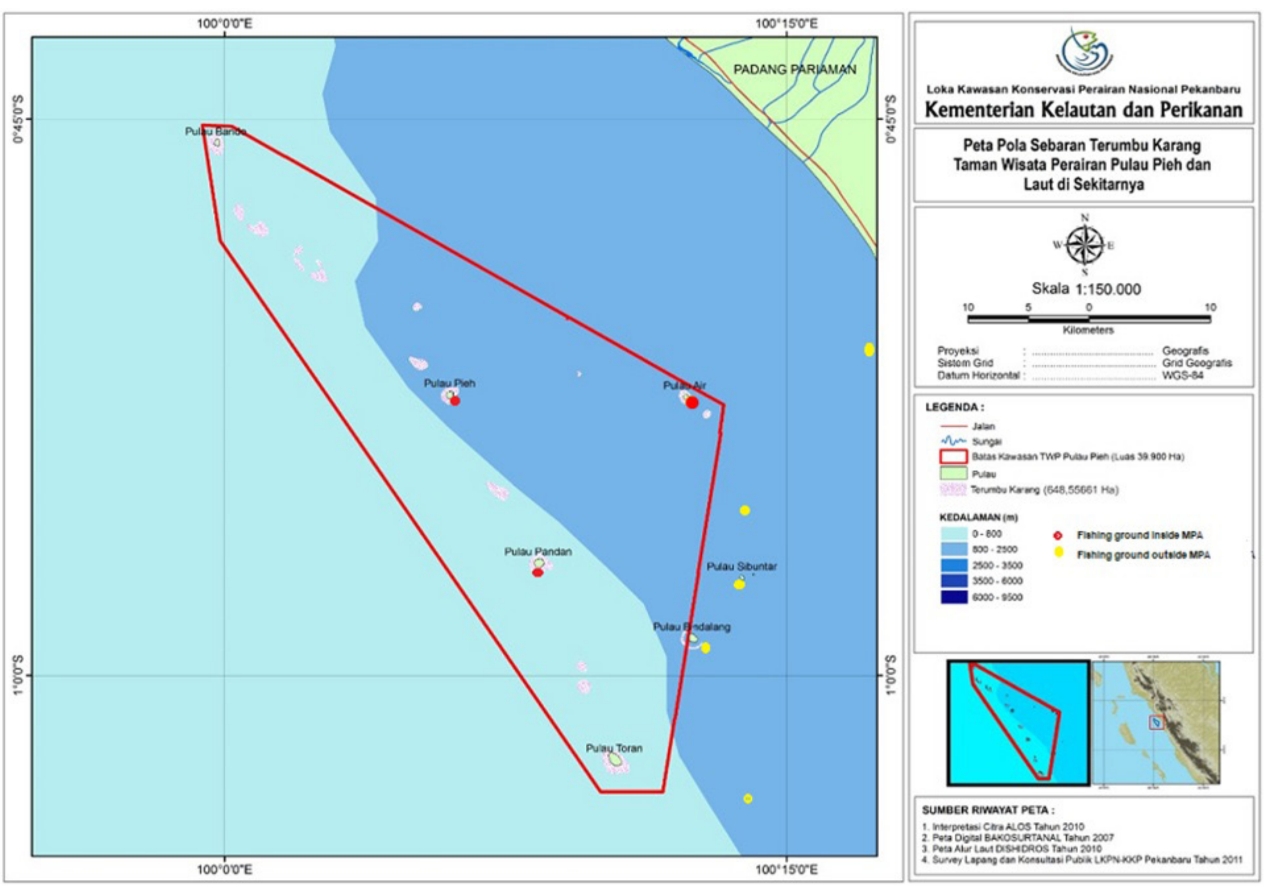

Figure 1. Pieh Marine Protected Area in the West Sumatera waters, including fishing ground area inside MPA (red dot) and outside MPA (yellow dot)

seafloor sand dunes, and sandy and rocky beaches. Deep reefs and sand dunes have become favorite hunting grounds for pisciverous reef fishes, including groupers and snappers. At least 105 species of corals were identified living in this MPA (LIPI 2014). There are about 86 species of reef fishes inhabiting coral reef area within Pieh MPA, with the maximum abundance of reef fishes was about 800 ind/ha and fish biomass about 760.65 kg/ha in 2019 (LKKPN Pekanbaru 2019). Oceanographic conditions in this MPA are highly influenced by the Indian Ocean dynamics. However, as there are a row of bigger islands (Mentawai Islands and Nias Islands) in front of Pieh Islands, high waves and strong currents from the Indian Ocean are reduced.

2.2. Data Collection

2.2.1. Catch Composition

Primary data on the catch composition of fish resources were acquired by conducting two fishing experiments in April 2020 and April 2021, utilizing hand lines and following the local fisherman's fishing activity for three days. To compare the condition of fish resources in protected and unprotected areas, fishing experiments were conducted simultaneously in two locations, inside Pieh MPA and outside Pieh MPA. The fishing ground in the MPA was inside the core zone of Pandan Island and the fishing grounds outside of the protected area were surrounding Bindalang Island, Sinyaru Island, Nyamuk Island, Pisang Island, and Sibunta Island (as denoted in Figure 1). Those small islands are closer to the mainland and become favorite fishing grounds for reef fishes. Fishing in the core zone area of Pandan Island is forbidden unless it is for research purposes with permission from the management authority.

2.2.2. Length-weight Data of *Epinephelus areolatus*

A total of 31 Epinephelus areolatus (squaretail grouper) were measured for fork-length and weight. E. areolatus was selected since the species was the most dominant grouper species landed in West Sumatra (Rachmawati and Puspasari 2015). Monthly data collected from various landing locations randomly sampled from fishing ground inside and outside the MPA. The collection of grouper data was carried out from May to December 2021.

2.3. Data Analysis

2.3.1. Catch per Unit Effort (CPUE) Analysis

The CPUE of total fishing experiments were then calculated following Gulland (1982). Fishing effort is the number of trips per vessel per day, where the vessel size used is quite similar, which is less than 5 gross tons. Fishing experiments were conducted using hand lines as the dominant fishing gear to catch reef fishes. The CPUE, size distribution, and species composition then were compared between inside MPA and outside MPA. Subsequently, the CPUEs between two areas were analyzed using *t*-test.

2.3.2. Species and Size Comparison

The difference of fish community composition and size composition between inside MPA and outside MPA were analyzed by comparing the frequencies of the samples using a chi-square test for categorical variables (p-value <0.05). Lower cut two sample *t*-test ($\alpha = 0.1$) was used to analyze the size difference between inside and outside MPA.

2.3.3. Biological Aspects

2.3.3.1. Length Distribution of *E. areolatus*

Size data were grouped into nine groups with an interval 2 cm between groups. The size frequency distribution data were then plotted to describe the size distribution.

2.3.3.2. Length at the First Maturity of *E. areolatus*

The length at first maturity (L_m) was analyzed by the equation (Froese and Binohlan 2000):

$$\mathrm{Log}_{10} L_m = 0.8979 * \log_{10} L\infty - 0.0782$$

where L_m is the length at first maturity and L_∞ is asymptotic length.

The length at first capture (L_c) was analyzed by the equation (Sparre and Venema 1992):

$$S\_CL = 1 / (1 + \exp(a - b * CL))$$

Where L_c is selectivity fishing gear, obtained from a/b, with a and b are constants, and CL is fish length.

3. Results

3.1. Comparison of Fish Abundance (CPUE) between Inside and Outside the MPA

Fishing experiments conducted inside and outside MPA showed that CPUE of reef fishes inside MPA are significantly higher than that outside MPA (p-value = 0.047). In 2020, the average of CPUE from hand line fishing in the core zone of Pandan Island was 7,6 kg/trip/vessel; meanwhile, CPUE from hand line operated outside MPA was about 3.07 kg/trip/vessel. The fishing experiment conducted in 2021 showed similar results as that in 2020, showing CPUE of hand line fishing inside MPA area was approximately two times higher than that outside MPA that are 8.6 kg/trip/vessel and 4.7 kg/trip/vessel, respectively (Figure 2).

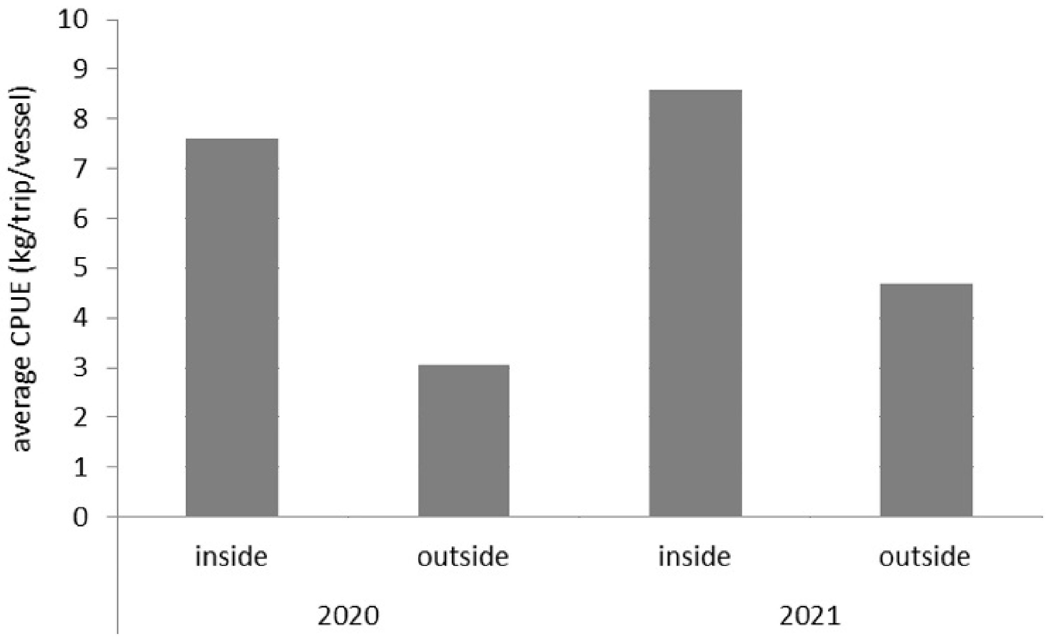

Figure 2. The average CPUE of the hand line operated inside and outside Pieh MPA in 2020 and 2021

3.2. Comparison of the Fish Composition

Fishing experiments showed that there is no significant difference in fish community composition between inside and outside MPA (p-value >0.05). The catch within MPA was composed of 11 groups of fish and the outside MPA catch was composed of 12 groups of fish (Table 1). Snappers and groupers dominated the catch in the outside MPA, meanwhile in the MPA area, trevallies, snappers, and groupers dominated the catch.

Fish size comparison was carried out for seven species, *E. areolatus, Cephalopholis argus, Lutjanus gibbus, L. russellii, Priacanthus* spp., *Upeneus* spp., and *Sphyraena* spp., which were dominantly found in both areas (Table 2). The minimum and maximum size of caught fishes were recorded. There was no clear pattern of fish size between inside and outside MPA, and the size varies between species. Comparison of dominant fish length did not show significant difference for all fish groups. However, *L. russellii* showed bigger size in the MPA area compared to the outside MPA area in the 10% significance level (p = 0.061). The minimum size of *C. argus* was similar between inside and outside MPA, but the maximum size inside MPA is larger than outside MPA. On the other hand, the minimum size of *E. areolatus* inside MPA is larger than one outside MPA. Snapper *L. gibbus* outside MPA were found in larger size, while *L. russellii* outside MPA were significantly smaller for

Table 1. Fish group composition inside and outside MPA

Fish names	Fish percentage (%)	
	Inside MPA	Outside MPA
Barracuda	6.02	0.81
Barramundi	0.05	-
Emperor	-	0.75
Goatfish	0.62	2.16
Grouper	25.07	33.52
Parrotfish	4.22	5.22
Red big eye	1.65	2.28
Snapper	22.97	41.85
Swordfish	4.34	0.35
Threadfin bream	-	7.29
Threadfin fish	-	1.45
Trevallies	32.59	3.67
Triggerfish	2.24	0.65
Wolf herring	0.22	-

Table 2. Comparing minimum and maximum sizes of fish inside and outside MPA

Species	Inside MPA		Outside MPA	
	min	max	min	max
C. argus (grouper)	17.0	33	17.3	20
E. areolatus (grouper)	15.5	32	10.3	50
L. gibbus (snapper)	28.0	35	45.0	49
L. russellii (snapper)	8.5*	47*	5.0*	19*
Priacanthus spp. (big red eye)	23.0	31	10.0	30
Upeneus spp. (goatfish)	14.0	26	9.0	30
Sphyraena spp. (barracuda)	46.0	70	11.2	52

*significantly different at $\alpha = 0.05$

both minimum and maximum size. The minimum and maximum size for *Priacanthus* spp. and *Sphyraena* spp. inside MPA showed larger size than one outside MPA. However, *Upeneus* spp. inside MPA showed larger minimum size but smaller maximum size than *Upeneus* spp. outside MPA.

3.3. Comparison of Biological Condition of Indicator Species (*E. areolatus*)

Epinephelus areolatus is one of dominant grouper species caught in the MPA area and outside the MPA area, becoming a target of fishermen because of its high economic value. The length and weight measurements of a total 31 individuals of *E. areolatus*, consisting of 11 individuals from MPA and 20 individuals from the adjacent areas, indicate the differences of biological conditions (Table 3). A two-sample *t*-test analysis has been applied to analyze the difference of the length and weight of *E. areolatus* populations. The analysis showed that both length and weight of those two populations are significantly different among others (p-value for length is 0.002 and p-value for weight is 0.037). In general, the samples collected from inside MPA were smaller than ones from outside MPA.

Table 3. The length-weight comparison of *E. areolatus* inside MPA and outside MPA

Species	Inside MPA		Outside MPA	
	length	weight	length	weight
Average	19.28	127.15	23.79	181.25
Minimum	12.90	46.00	18.90	84.00
Maximum	26.70	250.00	29.70	350.00

The length distribution of total samples showed the trend of majority size of each fish group, described by the length frequency analysis (Figure 3). The mid length of *E. areolatus* caught inside MPA were distributed from 13 cm to 27 cm with the majority of fish samples being the 13 cm and 21 cm of mid length. However, for the adjacent areas, the mid length of the length-frequency classes ranged from 19 cm to 29 cm with the majority of fish samples being in the 23 cm of mid length. The results showed that the length distribution of fish caught in the outside MPA are higher than those one caught inside the MPA.

Furthermore, our study reveals that most of the caught *E. areolatus* had spawned or matured (86.67%) and the length at first capture (L_c) was about 20.40 cm, which was higher than the length of first maturity (L_m = 16.76) value (Figure 4).

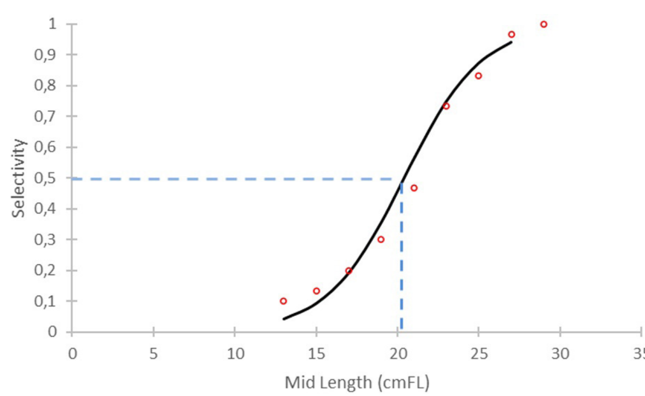

Figure 4. The length at first capture of *E. areolatus*.

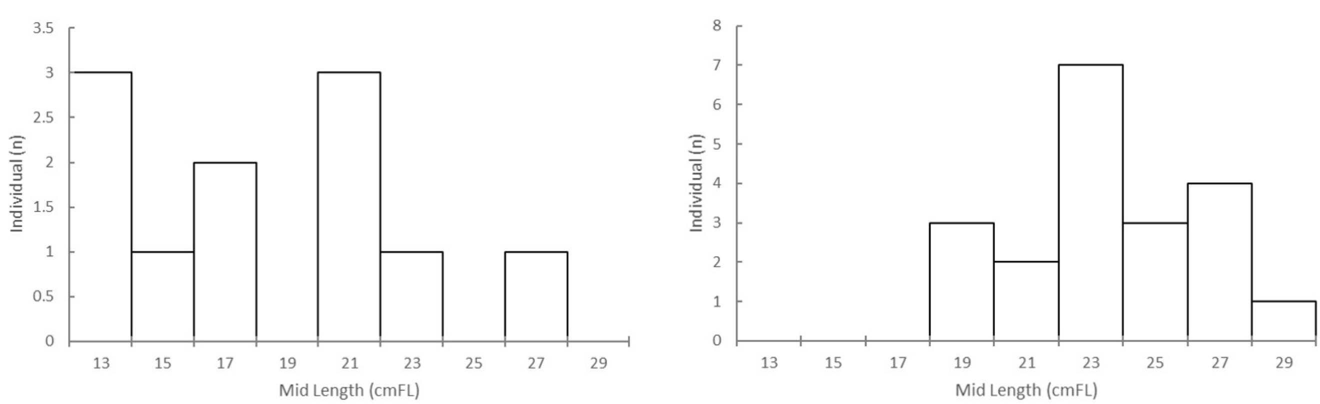

Figure 3. The length frequency distribution of *E. areolatus* in MPAs (left, N = 11) and adjacent areas (right, N = 20)

4. Discussion

4.1. Marine Protected Area Increase CPUE Two-fold Higher

Our results (Figure 2) confirmed the growing body of evidence regarding an increase in CPUE of reef fish where the fishing location is closer to the conservation area (Abesamis *et al.* 2006; McClanahan and Mangi 2000; Rakitin and Kramer 1996). Protected areas result in better condition of fish stock, due to limited exploitation and higher value of fish stocks, compared to its adjacent area (Harmelin-vivien *et al.* 2008; McClure *et al.* 2020).

Marine protected areas have rules on fishing activity inside their borders. The management measure that is mostly applied in MPA is to manage the area by using a zonation approach and to limit the fishing effort in the fishing zone. Surveillance and community participation have a big role in limiting fishing effort in the MPA areas. MPAs have significantly limited overfishing conditions. Yunanto *et al.* (2019) has shown that MPA has a lower fishing level index compared to unprotected ones. Limited fishing activity affected the pressure on the fish community and gave the opportunity to the fish community to grow, impacting on higher species richness and abundance (Harmelin-vivien *et al.* 2008).

Well-managed protected areas have higher biodiversity including benthic organisms and small fishes, which can restore the ecosystem complexity, become healthier than previous conditions, and provide a more complex food web (Sala and Giokumi 2018). Healthy and complex ecosystems provide top predators such as groupers with an abundant food supply to grow, leading to high fish abundant in that area.

4.2. The Composition is Roughly Similar with Some Unique Notes

The fish catch composition showed that the fishermen in the study areas targeted reef-associated fish (Table 1). The catch composition outside the MPA was dominated by grouper and snapper that inhabit deeper water. Meanwhile, fish caught in protected areas are dominated not only by grouper and snapper but also trevallies, which were caught in significant numbers, that have strong association with coral reefs. Lédée *et al.* (2015) recorded 98.8% of *Caranx ignobilis*, as a member of trevallies family, were found moving only in certain coral reef areas. Despite the difference of the fish catch dominance between inside and outside the MPA, in general, the species composition (Table 1) and size comparison (Table 2) are relatively similar. No significant difference in size composition as well as in species composition showed that the Pieh MPA existence has not yet had an impact on fishermen-targeted fish size and composition. However, there are possible reasons regarding the insignificant differences in fish size might be due to the use of similar selective fishing gear such as hand line with similar hook size. The fishermen used a similar size of hook to fish inside and outside MPA, resulting in the caught fish having similar range size. The effects of the Pieh MPA can be seen in the size of fish that have strong association with coral reefs, such as *L. ruselli, C. argus* and *Sphyraena* spp. (Table 2), that showed larger size in the protected area compared to the outside MPA, even though only *L. ruselli* showed a statistically significant difference. Further investigations on the impacts of Pieh MPA on fish size incorporating these species are essential but need to carefully assess the fishing gear type to avoid some biases of size comparison data.

4.3. Comparing the Biology of *E. areolatus*

Tabel 3 and Figure 5 showed the fish caught inside the MPA were mostly smaller compared to the MPA's adjacent areas. The curve of length distribution for fishes caught in the outside MPA did not show a normal shape; instead, it tended to be skewed to the right, indicating the number of larger size grouper is higher than its average (Pauly 1987). In the opposite site, *E. areolatus* caught within MPA showed left skewed length distribution, indicating smaller fish caught inside the MPA. Smaller size of the catch indicates the occurrence of fishing pressures in the past (Yemane *et al.* 2004). Fisheries statistical data showed that there was an increased effort to catch reef fishes around the study area since 1998 that used hand lines as selective fishing gear (Rachmawati *et al.* 2021), leading to the decrease of large fish composition. Figure 5 showed the trend of fishing effort around the study area.

Comparing the fish size with other locations based on the length of first maturity (L_m), the L_m value of *E. areolatus* in the study area is much less than the findings reported by Abdul Kadir *et al.* (2016) for *E. areolatus* from Pulau Kambing and Kuala Dungun fish landing ports, which were 32.6 cm and 35.7 cm, respectively, as well as by Pakoa (1998) for *E. areolatus* in Vanuatu, which was mature at 22 cm and reached a maximum length of 44 cm. Selective fishing in size using hand lines, which has been carried out for decades around study areas (Figure 1), led to the large size of groupers being removed from the population for several generations. The similar condition has been shown by demersal fisheries in the west coast of Scotland (Hunter *et al.* 2015), which showed the decrease in age and size maturation after decades of excessive harvest. Froese (2004) stated that one of the indicators of overfishing is the decrease of mature individuals. After the establishment of Pieh MPA in

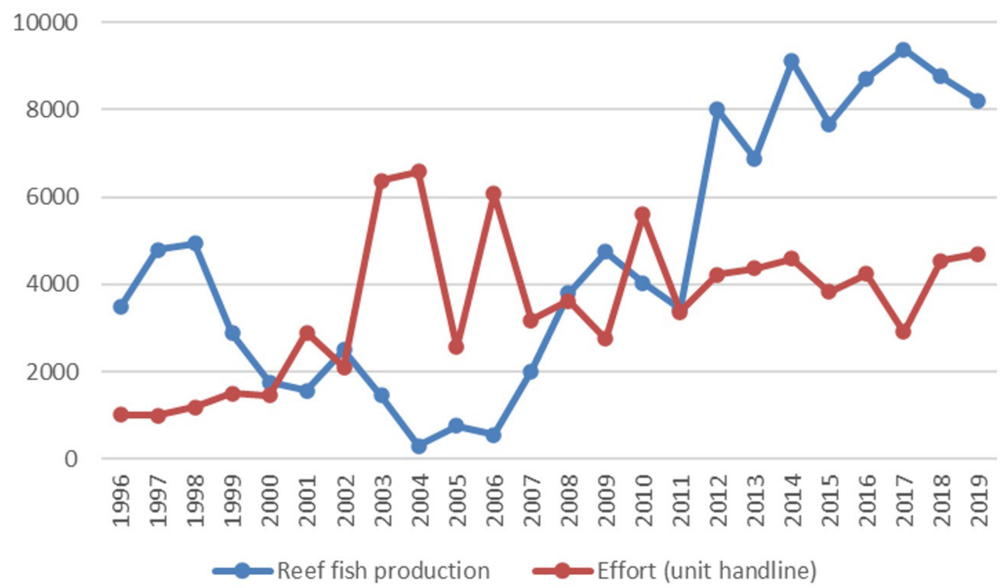

Figure 5. Trend of reef fish production and effort of fishing using handline

1994, the grouper fishing grounds were reduced, due to the regulation of protected areas. To maintain the stability of fish production, fishermen increase their fishing efforts (Figure 6) and increase the fishing depth to catch large fish.

In addition, the biological condition of *E. areolatus* cannot solely portray the importance of MPAs in the size range of the species, because there is an influence of compounding factors, such as fishing depth and selective fishing gear. Moreover, different sizes of groupers inhabit different depths and there is an ontogenetic on habitat changes for groupers (Giglio *et al.* 2014). Therefore, the use of *E. areolatus* as the only indicator to test the impact of MPA on fish size is not ideal and other species should be incorporated for future research.

A summary of this study shows that MPAs can improve fish biomass in protected zones. However, the impacts of overfishing in previous periods, especially in reducing fish size, are still significant and require more efforts in managing MPAs that should be integrated with fisheries management in order to recover the fish resources.

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