HAYATI
Journal of Biosciences

Vol. 29 No. 2, March 2022 245-254
DOI:10.4308/hjb.29.2.245-254
ISSN: 1978-3019
EISSN: 2086-4094

Reef Fish in the Mudflats of Kaledupa Island in Wakatobi National Park, Indonesia

Ernik Yuliana[1*], Adi Winata[2], Hasan Eldin Adimu[3], Yuni Tri Hewindati[4], Wibowo A. Djatmiko[5]

[1]*Department of Agriculture, Faculty of Science and Technology, Universitas Terbuka, Pamulang, Tangerang Selatan, Indonesia*
[2]*Department of Technique, Faculty of Science and Technology, Universitas Terbuka, Pamulang, Tangerang Selatan, Indonesia*
[3]*Department of Marine Science, Faculty of Fisheries and Animal Husbandry, Universitas Sembilanbelas November, Kolaka, Indonesia*
[4]*Department of Natural Sciences, Faculty of Science and Technology, Universitas Terbuka, Pamulang, Tangerang Selatan, Indonesia*
[5]*The Indonesian Tropical Institute (LATIN), Bogor, Indonesia*

ARTICLE INFO

Article history:
Received March 19, 2021
Received in revised form December 30, 2021
Accepted January 10, 2022

KEYWORDS:
diversity,
exploitation rate,
Kaledupa,
mudflats,
reef fish,
Wakatobi

ABSTRACT

Although frequently described as low-fertility or low-productivity habitat, coastal mudflats serve as important feeding grounds for fish. Many fish species from adjacent coral reefs, seagrass beds, or mangroves foraging periodically in mudflats. Because of this foraging behaviour, some local fishermen are known to utilize the mudflats to catch fish. However, the impact of this catching activities to the ecosystem has not been fully discovered. An examination of the fish community structure and levels of environmental stress had carried out in the mudflat ecosystem of the coast of Kaledupa Island in Wakatobi National Park (WNP), Indonesia. Two mudflat study sites were selected from the shore of Balasuna and Tampara villages located between mangroves and coral reefs. Data were sampled from the fish catch of local fishermen using fish fences (*sero*) installed in each mudflat area. Fish community structure was analyzed using diversity index and index of relative importance (IRI). ABC curves and species exploitation rate were used to assess the local environmental pressure. A total of 74 fish species were recorded from the mudflats of Kaledupa, which was found to be dominated by reef-associated fish species, comprising 63 species and accounting for 85% of the total catch. Additionally, although both sites had relatively high reef fish diversity, the obtained Clarke's W-statistic values were approximately 0, indicating that the local fish communities presented moderate levels of disturbance. Three out of five fish species with the highest IRI values were found to be over-exploited, namely *Siganus canaliculatus, Lethrinus ornatus*, and *Lethrinus variegatus.*

1. Introduction

Mudflats are described as low-fertility or low-productivity (Fanjul *et al.* 2011) coastal wetlands. At the other hand, coastal mudflats serve as important feeding grounds for fish when the high tide inundates them (Lee *et al.* 2013). Because of their shallow water column, the benthic process plays a more important role than the pelagic process in this ecosystem Furthermore, water substrates are essential for holding inorganic nutrients originating from the ocean and land runoff (Fanjul *et al.* 2011). Some fish species are periodically foraging for food in mudflats. The local inhabitants of Kaledupa Island, one of the largest islands in Wakatobi National Park (WNP), take advantage of these foraging patterns to catch a large number of fish. Usually, fishermen from the island catch coral reef or pelagic fish using fish fences (locally known as sero) or gill nets. Unfortunately, these methods for catching fish carry the risk of bycatch (i.e., the unintentional capture of non-target species, such as non-commercial or inedible fish), and this can threaten the sustainability of marine resources. Already, some shallow-water habitats in Wakatobi National Park have been adversely affected by the activities of the increasing human population (Azhar *et al.* 2019).

The WNP is a marine conservation area in Indonesia, officially established on July 30, 1996. WNP extends over an area of 1,390,000 ha, 97% of which is sea (Elliott *et al.* 2001), and, on account of its size, is included in the large-scale conservation category (Ban *et al.* 2017), and is at the center of the world biodiversity

---

* Corresponding Author
E-mail Address: ernik@ecampus.ut.ac.id

(Madduppa *et al.* 2020). Kaledupa Island is one of the islands in the WNP territory, and like the other islands in its vicinity (Wangi-wangi, Tomia, dan Binongko), it is characterized by mangrove ecosystems and mudflats. These habitats provide a protective environment for coral reefs, seagrass beds, and another ecosystems (Azhar *et al.* 2019) includes mudflats.

Fish diversity and sustainability in the WNP have received considerable attention since the fundamental objective of this park is to protect marine biodiversity. Fish diversity is an important indicator of fish stock security from which an acceptable level of fishing can be set (Yuliana *et al.* 2019), and thus studying reef fish diversity is necessary to identify the health status of coral reef ecosystems (Pet-Soede *et al.* 2001). In this case, abundance and biomass are two important indices for measuring reef fish diversity (Ault *et al.* 2013).

The present study aimed to analyze the fish community structure in the mudflats of Kaledupa Island. The analyses included the estimation of fish species composition and diversity indices, along with the assessment of the environmental stress suffered by local fish communities using ABC curves and by calculating the rate of exploitation of certain species.

2. Materials and Methods

2.1. Study Site

This research was conducted in the water bodies adjacent to Kaledupa Island at two different sites: (a) Balasuna Village, located on the east side of the island, and (b) Tampara Village on the west side (Figure 1). The two villages were selected as two representative regions of this island, as they have different conditions; for example, Balasuna faces relatively closed waters originating from a small strait between Kaledupa Island and Hoga Island, while Tampara faces more open waters.

2.2. Collecting Data

Data were collected over a period of 6 months and comprised observations of the fishermen's catches collected from the fish fences set in mudflat areas at the front of mangrove forests. The species, number of individuals, their biomass, and catch amount and composition were recorded.

2.3. Data Analyzed

The species composition was analyzed using the index of relative importance (IRI) (Hu *et al.* 2019).

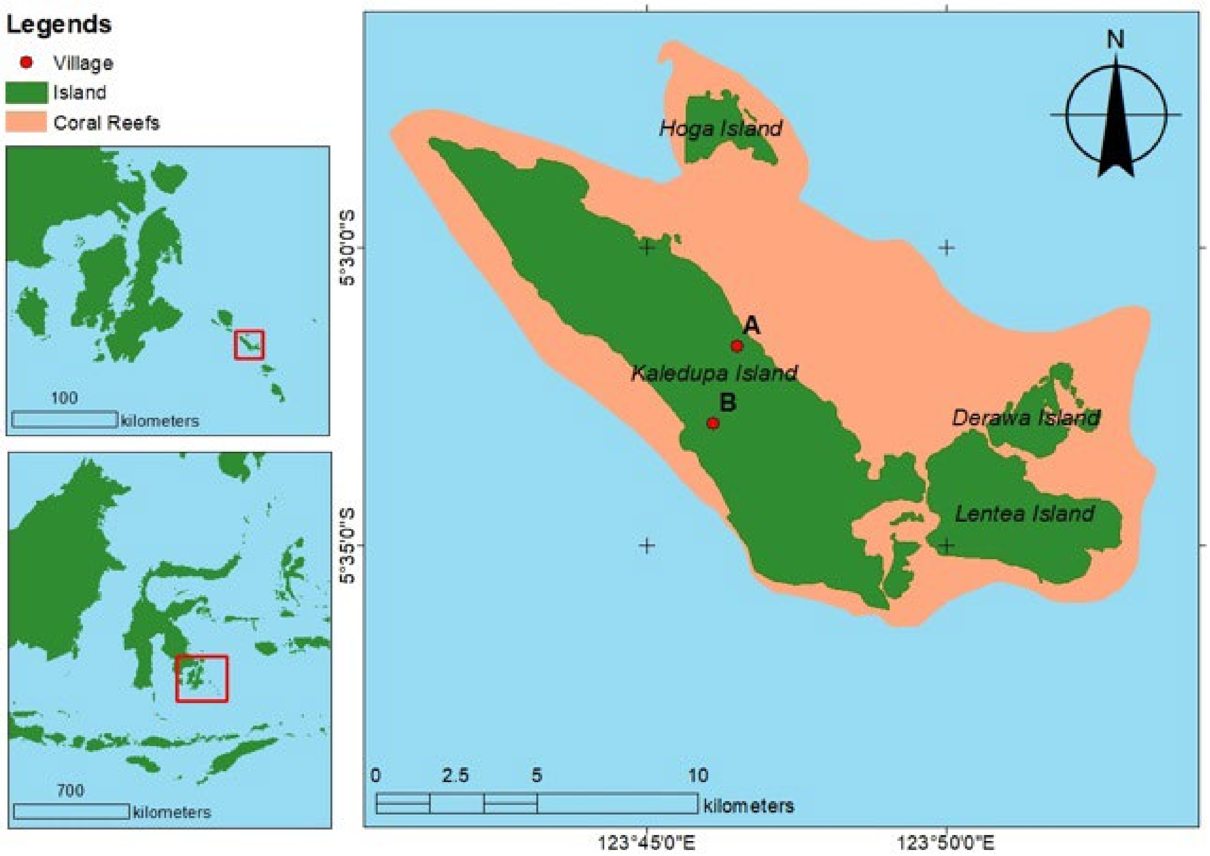

Figure 1. The research sites in Kaledupa Island: Balasuna Village (A) and Tampara Village (B) within Wakatobi National Park's territory, South-east Sulawesi, Indonesia

Fish diversity analysis was based on the indices of species diversity, evenness, and richness.

The species diversity index (H') was measured using the following formula by Shannon and Wiener (Odum 1971):

$$H' = p_i \ln p_i \tag{1}$$

Where p_i is the proportion or the relative abundance (ni/N) of a given species, ni is the number of individuals of that specified species (i), and N is the total number of individuals in a given sample.

The species evenness index (E) was calculated according to the following equation (Pielou 1966):

$$E = \frac{H'}{\ln S} \tag{2}$$

Where H' is the species diversity index, and S represents the number of species in a community.

The community similarity index (IS) was determined according to Jaccard's formula, as represented in the following equation:

$$IS = \frac{a}{a+b+c} \tag{3}$$

Where a represents the number of individuals in location A, b is the number of individuals in location B, and c is the number of individuals in both locations (A and B).

The abundance-biomass comparison (ABC) curve was used to assess the level of environmental disturbance. In this method, species are ranked according to their biomass and abundance, and then plotted along the log-transformed x-axis (Di Bagno *et al.* 2020). Clarke's W-statistic was calculated using the equation (Meire and Dereu 1990):

$$W\text{-}statistic = \frac{\sum_{i=1}^{n}(B_i - A_i)}{N} \tag{4}$$

Where B_i and A_i refer to the biomass and abundance of species i, respectively. Values of the W-statistic range from -1 to +1, indicating the state of the environment from severely disturbed (W = -1) to pristine (W = +1); hence, values close to 0 indicate moderate disturbance (Clarke 1990; Yemane *et al.* 2005; Di Bagno *et al.* 2020).

The index of relative importance (IRI) was calculated with the following equation (Hu *et al.* 2019):

$$IRI = (N_i + W_i) \times F_i \tag{5}$$

Where N_i represents the relative abundance, Wi represents the relative biomass, and F_i represents the relative frequency.

The fish exploitation rate (Ex) was calculated based on mortality estimation. Natural mortality estimation was carried out using the FISAT II software with Pauly's M Equation method, total mortality was measured with the long-converted-catch curve method (Pauly 1983; Gayanilo *et al.* 2005) fishing mortality rate was determined using the relationship $F = Z - M$. Finally, the rate of exploitation was determined using the following equation:

$$Ex = \frac{F}{Z} \tag{6}$$

Where F represents fishing mortality, and Z represents total mortality. The rational and sustainable exploitation rate (Ex) for a body of water should be under the value of 0.5 (Sparre and Venema 1998).

3. Results

3.1. Fish Diversity

A total of 74 fish species were identified from the sampling of local fishermen's catches at the two study sites (Balasuna and Tampara). Furthermore, 63 of those species consisted of reef-associated fish, and the remaining 11 species were pelagic and demersal fish (Table 1). It is evident that reef fish represent a larger proportion than any other group (Figure 2).

Likewise, the five species with the highest IRI were all reef-associated fish. Although three of these species are members of Lethrinidae, the highest IRI belongs to *Siganus canaliculatus* (Siganidae), with a value of 400.03 (Table 2). Lethrinidae, along with Mullidae and Scaridae, were the most represented families, with each recording six species (Table 1).

3.2. Comparison between Two Sites

The two study sites recorded almost similar numbers of species, with 58 species in Balasuna and 59 species in Tampara (Table 3); however, only 44 of the 74 species were present in both sites (Table 4). Furthermore, the Shannon-Wiener index of diversity values and species evenness index values at the two sites were also similar (H': 2.89 and 2.93, and E: 0.71 and 0.72, for Balasuna and Tampara respectively). However, the Tampara site recorded a greater number of individuals, as well as larger biomass values (Table 3). These differences are reflected in the IS value of 59.46%, meaning that the similarity of the fish community structures of the two locations is only 60% (Table 3).

Table 1. The species composition and its distribution in the sampling sites

Family/species	Common name	Fish group	Balasuna site	Tampar site	Number of Individuals	Frequency	Biomass (g)	Index of relative importance (IRI)
Acanthuridae								
Acanthurus lineatus	Lined surgeonfish	reef-associated	+	-	2	1	140	140
Acanthurus nigricauda	Epaulette surgeonfish	reef-associated	+	-	4	2	347	347
Naso lituratus	Orangespine unicornfish	reef-associated	-	+	4	1	259	259
Atherinidae								
Atherinomorus duodecimalis	Tropical silverside	demersal	-	+	20	3	288	288
Atherinomorus lacunasus	Wide-banded hardyhead silverside	reef-associated	-	+	12	2	181	181
Balistidae								252
Balistapus undulatus	Orange-lined triggerfish	reef-associated	+	-	2	2	252	225
Rhinecanthus verrucosus	Blackbelly triggerfish	reef-associated	+	-	1	1	225	
Belonidae								
Tylosurus crocodilus	Hound needlefish	reef-associated	+	+	17	6	2,220	2,220
Carangidae								
Carangoides chrysophrys	Longnose trevally	reef-associated	+	-	3	1	636	636
Carangoides ferdau	Blue trevally	reef-associated	+	+	21	5	2,225	2,225
Caranx hippos	Crevalle jack	reef-associated	-	+	2	1	219	0.02
Caranx tille	Tille trevally	reef-associated	+	+	28	7	2,175	2.43
Chaetodontidae								
Chaetodon vagabundus	Vagabond butterflyfish	reef-associated	+	+	9	7	695	0.71
Diodontidae								
Diodon holocanthus	Longspined porcupinefish	reef-associated	+	+	15	8	5,062	3.75
Eleotridae								
Oxyeleotris lineolata	Sleepy cod	demersal	-	+	20	1	2,424	0.20
Ephippidae								
Platax pinatus	Dusky batfish	reef-associated	+	+	13	5	1,348	0.94
Platax orbicularis	Orbicular batfish	reef-associated	+	+	10	4	405	0.31
Exocoetidae								
Cypselurus naresii	Pharao flyingfish	pelagic	+	+	18	8	1,368	1.69
Gerreidae								
Gerres filamentosus	Whipfin silver-biddy	demersal	+	+	60	14	5,927	11.11
Gerres oyena	Common silver-biddy	reef-associated	+	-	2	1	363	0.05
Haemulidae								
Diagramma melanacrum	Blackfin slatey	bentho-pelagic	+	-	4	2	566	0.17
Plectorhinchus lineatus	Yellowbanded sweetlips	reef-associated	+	+	67	12	7,183	10.46
Pomadasys furcatus	Banded grunter	reef-associated	+	+	13	4	964	0.70

Table 1. Continued

Family/species	Common name	Fish group	Balasuna site	Tampar site	Number of Individuals	Frequency	Biomass (g)	Index of relative importance (IRI)
Hemiramphidae								
Hemiramphus far	Black-barred halfbeak	reef-associated	+	-	8	3	677	0.39
Hyporhamphus quoyi	Quoy's garfish	pelagic-neritic	+	+	21	6	819	0.91
Hyporhamphus affinis	Tropical halfbeak	reef-associated	+	-	2	2	227	0.08
Holocentridae								
Myripristis berndti	Blotcheye soldierfish	reef-associated	-	+	1	1	52	0.01
Myriptristis amaena	Brick soldierfish	reef-associated	-	+	2	1	72	0.01
Sargocentron cornutum	Threespot squirrelfish	reef-associated	-	+	1	1	43	0.01
Labridae								
Cheilio inermis	Cigar wrasse	reef-associated	-	+	2	1	57	0.01
Choerodon anchorago	Orange-dotted tuskfish	reef-associated	+	+	114	18	8,989	23.56
Choerodon cephalotes	Purple tuskfish	reef-associated	+	-	1	1	237	0.03
Thalassoma hardwicke	Sixbar wrasse	reef-associated	+	-	1	1	47	0.01
Leiognathidae								
Gazza dentex	Ovoid toothpony	demersal	+	+	12	4	1,075	0.61
Lethrinidae								
Lethrinus erythropterus	Longfin emperor	reef-associated	+	+	11	5	2,480	1.26
Lethrinus genivittatus	Longspin emperor	reef-associated	+	+	6	4	646	0.33
Lethrinus harak	Thumbprint emperor	reef-associated	+	+	505	36	73,179	295.42
Lethrinus lentjan	Pink ear emperor	reef-associated	-	+	4	1	550	0.04
Lethrinus ornatus	Ornate emperor	reef-associated	+	+	172	19	26,978	52.73
Lethrinus variegatus	Slender emperor	reef-associated	+	+	210	18	11,864	38.07
Lutjanidae								
Lutjanus fulviflamma	Dory snapper	reef-associated	+	+	15	7	2,539	1.78
Lutjanus monostigma	One-spot snapper	reef-associated	-	+	7	3	928	0.22
Lutjanus quinquelineatus	Five-lined snapper	reef-associated	+	-	3	1	294	0.05
Mugilidae								
Ellochelon vaigiensis	Squaretail mullet	reef-associated	+	+	21	6	4,707	2.40
Mullidae								
Mulloidichthys martinicus	Yellow goatfish	reef-associated	+	+	4	2	492	0.12
Mulloidichthys flavolineatus	Yellowstripe goatfish	reef-associated	+	+	130	25	10,624	40.94
Parupeneus barberinus	Dash-and-dot goatfish	reef-associated	+	+	36	5	2,615	2.21
Parupeneus crassilabris	Ray-finned fishes	reef-associated	+	+	71	15	3,838	10.73
Parupeneus cyclostomus	Gold-saddle goatfish	reef-associated	+	+	90	14	6,976	14.91
Upeneus tragula	Freckled goatfish	reef-associated	+	+	8	4	901	0.53

Table 1. Continued

Family/species	Common name	Fish group	Balasuna site	Tampar site	Number of Individuals	Frequency	Biomass (g)	Index of relative importance (IRI)
Nemipteridae								
Scolopsis aurata	Yellowstripe monocle bream	reef-associated	+	-	1	1	255	0.03
Scolopsis ciliata	Saw-jawed monocle bream	reef-associated	+	+	116	18	7,050	19.93
Scolopsis lineata	Striped monocle bream	reef-associated	+	+	55	16	2,622	6.88
Scolopsis xenochroa	Oblique-barred monocle bream	reef-associated	+	+	12	5	718	0.51
Paralichthyidae								
Pseudorhombus dupliocellatus	Ocellated flounder	demersal	-	+	1	1	28	0.01
Platycephalidae								
Cymbacephalus beauforti	Crocodile fish	reef-associated	+	+	5	3	2,446	0.52
Inegocia japonica	Japanese flathead	demersal	-	+	0	1	0	0.03
Plotosidae								
Plotosus canius	Gray eel-catfish	demersal	+	+	2	1	214	0.02
Scaridae								
Leptocerus vaigiensis	Marbled parrotfish	reef-associated	+	+	46	11	5,629	7.70
Scarus croicensis	Striped parrotfish	reef-associated	-	+	2	1	326	0.02
Scarus dimidiatus	Yellowbarred parrotfish	reef-associated	+	+	21	8	3,014	2.49
Scarus ghobban	Blue-barred parrotfish	reef-associated	+	-	2	1	450	0.06
Scarus psittacus	Common parrotfish	reef-associated	+	+	4	2	544	0.13
Scarus quoyi	Quoy's parrotfish	reef-associated	+	+	5	2	592	0.15
Scarus schlegeli	Yellowband parrotfish	reef-associated	+	+	23	7	1,286	1.44
Serranidae								
Epinephelus bleekeri	Duskytail grouper	demersal	+	+	6	4	1,403	0.53
Siganidae								
Siganus canaliculatus	White-spotted spinefoot	reef-associated	+	+	808	40	71,892	400.02
Siganus guttatus	Orange-spotted spinefoot	reef-associated	+	+	64	11	21,014	18.09
Siganus spinus	Little spinefoot	reef-associated	+	+	161	16	8,472	26.29
Siganus virgatus	Barhead spinefoot	reef-associated	+	+	45	7	2,212	3.29
Sphyraenidae								
Sphyraena barracuda	Great barracuda	reef-associated	+	+	7	4	1,707	0.64
Sphyraena obtusata	Obtuse barracuda	reef-associated	+	-	1	1	76	0.02
Toxotidae								
Toxotes jaculatrix	Banded archerfish	reef-associated	+	+	36	6	3,460	2.51
Zanclidae								
Zanclus cornutus	Moorish idol	reef-associated	-	+	1	1	34	0.01

+: present, -: absent

3.3. Environmental Disturbance

The water quality of the research location was classified as good (Table 5). Of the three water quality parameters measured, two (pH and temperature) were in accordance with the Water Quality Standards for Marine Biota (Indonesian State Minister of the Environment Decree no. 51/2004).

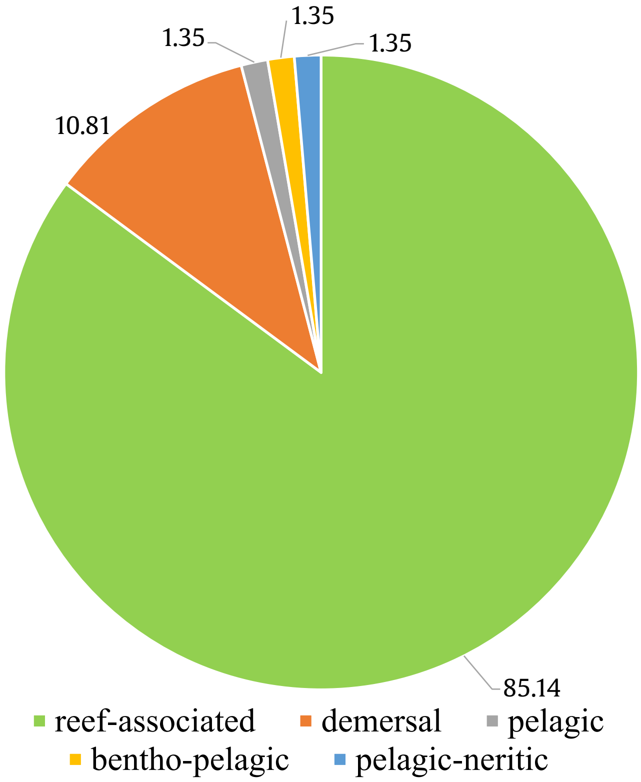

Figure 2. Reef fish proportion in the total fish catches (%)

However, the ABC curves obtained for the two study sites appeared to be almost entirely overlapped between the abundance line and biomass line, implying that the fish communities of both locations were moderately disturbed (Figure 3 and 4). Furthermore, this conclusion is confirmed by the W-statistic value, which was approximately 0 (W = 0.0136 for Balasuna, and W = -0.0002 for Tampara).

One form of environmental pressure in aquatic environments is the over-exploitation of target fish communities. Such effects can be detected by measuring the fish exploitation rate, obtained from the analysis of mortality based on the size of the fish catch. The analysis of the exploitation rate revealed that three of the five fish species with the highest IRI values were over-exploited (Table 6), namely *S. canaliculatus* (Ex = 0.55), *Lethrinus ornatus* (Ex = 0.65), and *L. variegatus* (Ex = 0.57). These results indicate that Kaledupa waters at both study sites have been over-exploited.

4. Discussion

Mudflats, which are part of coastal ecosystems, are occupied by fish species that are not specifically associated with these areas. Our study revealed that 63 spp. (85.13%) out of 74 spp. recorded were categorized as reef-associated fish. Other study on

Table 2. Five fish species with the highest IRI

Fish species	Common Name (English)	IRI
Siganus canaliculatus	White-spotted spinefoot	400.03
Lethrinus harak	Thumbprint emperor	295.44
Lethrinus ornatus	Ornate emperor	52.73
Mulloidichthys flavolineatus	Yellowstripe goatfish	40.95
Lethrinus variegatus	Slender emperor	38.07

Table 4. Matrix of the fishes' presence in Balasuna and Tampara

Fish species presence in the study sites		Tampara	
		Presence	Absence
Balasuna	Presence	44 (a)	14 (b)
	Absence	15 (c)	0 (d)

Table 3. The numbers of fish species, numbers of fish individuals, biomass, and species diversity in Balasuna and Tampara

Study sites	Total number of species	Total Number of Individuals	Total Biomass (g)	Species diversity (*H'*)	Species evenness (*E*)	Community similarity (*IS*)
Balasuna	58	1,393	162,005	2.89	0.71	59.46%
Tampara	59	1,837	171,397	2.93	0.72	

Table 5. Assessments of water quality in Tampara and Balasuna

Water quality	Tampara				Balasuna			
	U	M	L	Mean values	U	M	L	Mean values
pH	7.33	7.23	7.70	7.42	7.30	7.97	7.00	7.42
Temperature (°C)	28.67	27.67	29.33	28.56	29.00	28.3	28.70	28.67
TDS (mg/L)	84	82	86	84	87	86	86	86

U = upper (landward) zone, M = middle zone, L = lower (seaward) zone

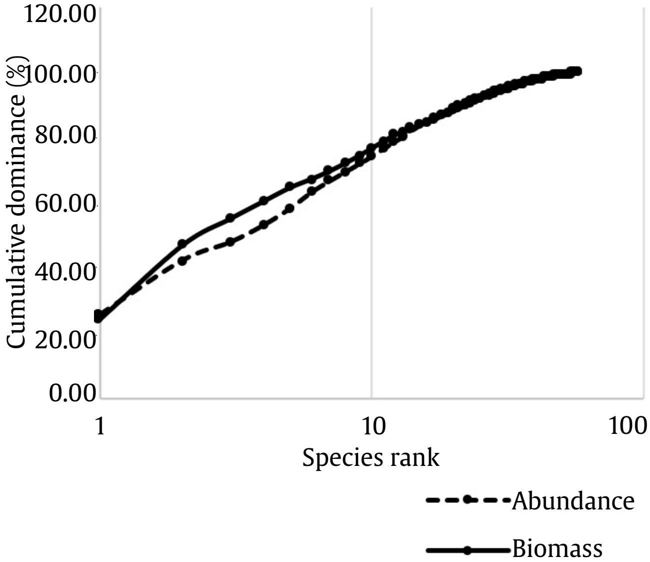

Figure 3. The comparison of abundance-biomass curves in the Balasuna site (W = 0.0136)

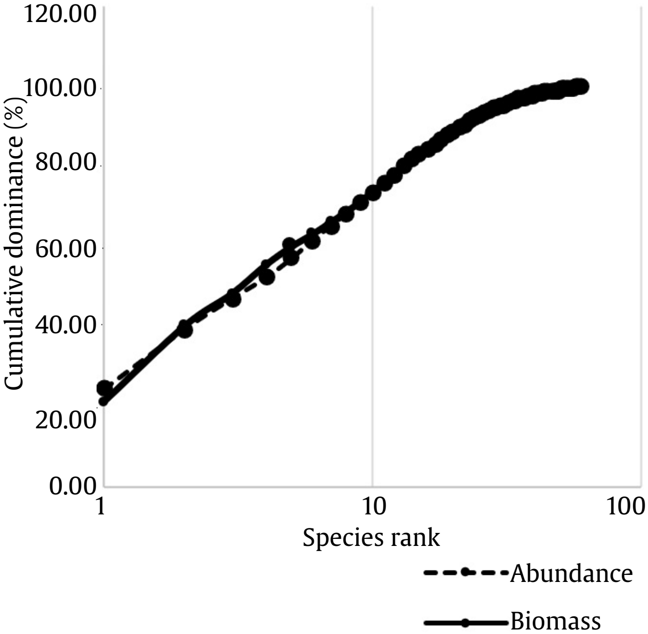

Figure 4. The comparison of abundance-biomass curves in the Tampara site (W = -0.0002)

Table 6. Exploitation rate for five fish species with highest IRI value

Species	Growth parameters			Mortality			Ex
	L_∞ (cm)	k (year^{-1})	t_0 (year)	M (/year^{-1})	(year^{-1})	Z (year^{-1})	
Siganus canaliculatus	30.76	0.74	-0.22	1.20	1.48	2.68	0.55
Lethrinus harak	31.52	0.50	-0.32	0.92	0.87	1.79	0.48
Lethrinus ornatus	31.52	0.55	-0,29	0.98	1.82	2.80	0.65
Mulloidichthys flavolineatus	27.34	0.53	-0.32	1.00	0.71	1.71	0.41
Lethrinus variegatus	21.05	0.47	-0.38	0.99	1.31	2.30	0.57

marginal habitats, e.g. near shore habitats around coral reef margins, of Hoga Island of Wakatobi, records many fish species shuttle between areas as the tides change. Some reasons of such shuttling behavior, as suggested, were to avoid larger predator, to access a wider range of foraging areas, and to reduced locomotion costs by exploiting natural tidal flows (Bennett 2010).

The mudflats in our two study sites were located between the mangrove forests and coral reefs. Such situation indicates that there is a close ecological relationship between coral reefs, mangroves, and mudflat ecosystems in Kaledupa Island.

This study revealed that the fish assemblage in the Kaledupa mudflats is dominated by reef-associated fish species. This is related to the nature of the WNP waters, which contain a large coral reef area, even though it has decreased from 2,217 ha to 2,039 ha between 2002 and 2016 (Azhar *et al.* 2019). This loss of reef coverage is suspected to be caused by destructive fishing activities, such as bombs and poisons (Azhar *et al.* 2019). Although preventive and monitoring measures are being taken, this decline of coral reef areas is thought to affect fish diversity (Pet-Soede *et al.* 2001).

However, relatively high fish diversity was still recorded at the two study sites on Kaledupa Island. The Shannon-Wiener diversity index (*H'*) values were close to 3 (Table 3), which is considered to be moderate to high. As a comparison, *H'* values for mudflat's fish assemblage in Klang, Malaysia ranged from 2.77 to 3.12 (Lee *et al.* 2013). Meanwhile, the assessment of fish communities in the lower Gianjiang River revealed that the values of the diversity index varied between 1.54 and 2.93 (Hu *et al.* 2019).

These conditions should be maintained as they greatly contribute to the high fish diversity currently observed in the surrounding area. The findings of this study indicate that fishing activities in Kaledupa are generally under control. Most fishermen in the two villages use traditional and passive fishing gear (especially *sero*) to minimize habitat disturbance and to conserve reef fish stocks. Unfortunately, a small proportion of local fishermen still utilize bombs and poison. The main disturbance to the coral reefs came from human (high and destructive fishing, pollution) and nature (sedimentation and climate change) (Hughes *et al.* 2012). The exact potential impacts of these threats are still unclear in many cases, thus making effective conservation more difficult (Madduppa *et al.* 2020).

As previously mentioned, some levels of disturbance occurred at both sites, as confirmed by the obtained ABC curves and Clarke's W-statistic values. Theoretically, ABC curves represent the two states between the "r" and "k" strategies of the evolutionary strategy theory. Positive W-statistic values (approximately +1) indicate that the biomass curve lies above the abundance curve, describing an undisturbed state where the k-selected species (with a large body size, but low in numbers) dominate the community, and vice versa (Clarke 1990; Yemane *et al.* 2005; Di Bagno *et al.* 2020). The W-statistic values obtained for the two sites were close to 0, demonstrating that the studied mudflat ecosystems were under moderate disturbance, although Balasuna was slightly less affected than Tampara.

Lies about the centre of the 'Coral Triangle' region, the WNP has a rich and abundant coral reef ecosystem (McMellor and Smith 2013). In turn, Government Regulation of the Republic of Indonesia no. 50/2011 concerning the National Tourism Development Master Plan 2010-2025 has declared the WNP as one of the National Tourism Strategic Areas (Wijaya and Damanik 2020). At the other hand, the rise of marine tourism can leads to coastal marine pollution, either from ship pollution, white (plastic) pollution, domestic waste generated by human activities, including tourism (Zheng dan Liu 2021). Therefore, it is necessary to balance the activities of tourism and fisheries to prevent them from harming each other (Yuliana *et al.* 2019).

However, pressure on fish communities also originates from fishing activities, as shown by the exploitation rates obtained from several dominant fish species (higher than 0.5), indicating a slightly over-exploited population. As suggested by many authors (e.g. Pauly 1983) optimal exploitation rate (E_{opt}) for fishing fish stock is less than or equal to 0.5.

Although sampling in this study was carried out on the catch of fishermen who used passive fishing gear, there are further fishing pressures arising from other types of fishing gear used around Kaledupa Island. Such situation needs to be resolved, both by Park management and other stakeholders including fishermen. Yuliana *et al.* (2019) suggest at least three policy recommendations to control over-exploitation, e.g. 1) educate fishers to build their awareness to catch adult fish only, 2) regulate fishing effort by setting mesh size limits of fishnet, 3) increase the monitoring of fishing activities.

Acknowledgements

The authors are grateful to the Universitas Terbuka for providing research funding through the fundamental research scheme. We also thank the authorities of Wakatobi National Park for granting permission to conduct our research at the study site. Finally, we would like to thank the anonymous reviewer for the valuable comments and criticism that contributed to the substantial improvement of the manuscript.

References

Ault, J.S., Smith, S.G., Bohnsack, J.A., Luo, J., Zurcher, N., McClellan, D.B., Ziegler, T.A., Hallac, D.E., Patterson, M., Feeley, M.W., 2013. Assessing coral reef fish population and community changes in response to marine reserves in the dry tortugas, *Florida, USA. Fish. Res.* 144, 28–37. https://doi.org/10.1016/j.fishres.2012.10.007

Azhar, A., Damar, A., Bengen, D.G., Atmadipoera, A.S., 2019. Shallow water marine habitat mapping of Kaledupa Island using integrating tradisional ecological knowledge and multispectral image classification. *IOP Conference Series: Earth and Environmental Science.* 241, 1-10. https://doi.org/10.1088/1755-1315/241/1/012038

Ban, N.C., Davies, T.E, Aguilera, S.E., Brooks, C., Cox, M., Epstein, G., Evans, L.S., Maxwell, S.M., Nenadovic, M., 2017. Social and ecological effectiveness of large marine protected areas. *Glob. Environ. Chang.* 43, 82–91. https://doi.org/10.1016/j.gloenvcha.2017.01.003

Bennett, W., 2010. Extreme physiology of intertidal fishes of the Wakatobi. in: Clifton, J., Unsworth, R.K.F., Smith, D.J., (Eds.), Marine Research and Conservation in the Coral Triangle: the Wakatobi National Park. Operation Wallacea and Gov't of Wakatobi Regency, Wakatobi. pp. 108–124.

Clarke, K.R., 1990. Comparisons of dominance curves. *J. Exp. Mar. Bio. Ecol.* 138, 143–157. https://doi.org/10.1016/0022-0981(90)90181-B

Di Bagno, E., Battisti, C., Zullo, F., Amori, G., 2020. Applying abundance/biomass comparison curves to small mammals: a weak tool for detect urbanization-related stress in the assemblages? *Folia Oecologica.* 47, 10–15. https://doi.org/10.2478/foecol-2020-0002

Elliott, G., Mitchell, B., Wiltshire, B., Manan, I.A., Wismer, S., 2001. Community participation in marine protected area management Wakatobi National Park, Sulawesi, Indonesia. *Coast. Manag.* 29, 295–316.https://doi.org/10.1080/089207501750475118

Fanjul, E., Bazterrica, M.C., Escapa, M., Grela, M.A., Iribarne, O., 2011. Impact of crab bioturbation on benthic flux and nitrogen dynamics of Southwest Atlantic intertidal marshes and mudflats. *Estuar. Coast. Shelf Sci.* 92, 629–638. https://doi.org/10.1016/j.ecss.2011.03.002

Gayanilo, F.C., Sparre, F., Pauly, D., Gayanilo, F.C.Jr., Sparre, P., Pauly, D., 2005. FAO-ICLARM Stock Assessment Tools II (FiSAT II). Revised version. User's guide. FAO, Rome.

Hu, M., Wang, C., Liu, Y., Zhang, X., Jian, S., 2019. Fish species composition, distribution and community structure in the lower reaches of Ganjiang River, Jiangxi, China. *Sci. Rep.* 9, 1–13. https://doi.org/10.1038/s41598-019-46600-2

Hughes, S., Yau, A., Max, L., Petrovic, N., Davenport, F., Marshall, M., McClanahan, T.R., Allison, E.H., Cinner, J.E., 2012. A framework to assess national level vulnerability from the perspective of food security: the case of coral reef fisheries. *Environ. Sci. Policy*. 23, 95-108. https://doi.org/10.1016/j.envsci.2012.07.012

Lee, S.L., Chong, V.C., Loh, K.H., Yurimoto, T., 2013. Are intertidal mudflat communities (fish and shrimp) affected by cockle culture? *Malaysian J. Sci.* 32, 107–116. https://doi.org/10.22452/mjs.vol32no3.10

Madduppa, H.H., Koropitan, A.F., Damar, A., Subhan, B., Taufik, M, Minsaris, L.O.A., Taurusman, A.A., Ramli, A., Purwanto, A.B., 2020. Ecological vulnerability of coral reef ecosystem in Wakatobi National Park during Indian ocean dipole event. *HAYATI J. Biosci.* 27, 57–70. https://doi.org/10.4308/hjb.27.1.57

McMellor, S., Smith, D.J., 2013. Coral reefs of the Wakatobi: Abundance and biodiversity. in: Clifton, J., Unsworth, R.K.F., Smith, D.J., (Eds.), Marine Research and Conservation in the Coral Triangle. Operation Wallacea and Gov't of Wakatobi Regency, Wakatobi. pp. 19–33.

Meire, P.M., Dereu, J., 1990. Use of the abundance/biomass comparison method for detecting environmental stress: some considerations based on intertidal macrozoobenthos and bird communities. *J. Appl. Ecol.* 27, 210–223. https://doi.org/10.2307/2403579

Odum, E.P., 1971. Fundamentals of Ecology, Third ed. Saunders College, Athens.

Pauly, D., 1983. Some simple methods for the assessment of tropical fish stocks. In: FAO. Fisheries Technical Paper. FAO, Rome. pp. 52.

Pet-Soede, C., Van Densen, W.L.T., Pet, J.S., Machiels, M.A.M., 2001. Impact of Indonesian coral reef fisheries on fish community structure and the resultant catch composition. *Fish. Res.* 51, 35–51. https://doi.org/10.1016/S0165-7836(00)00236-8

Pielou, E.C., 1966. The measurement of diversity in different types of biological collections. *J. Theor. Biol.* 13, 131–144. https://doi.org/10.1016/0022-5193(66)90013-0

Sparre, P., Venema, C.S., 1998. Introduction to tropical fish stock assessment. Part I: Manual. FAO Tech. Pap, Rome.

Wijaya, W., Damanik, J., 2020. Ecotourism study on ecotourism development in Kapota Island, Wakatobi Regency, Southeast Sulawesi Province. *E-Journal Tour.* 7, 300–322. https://doi.org/10.24922/eot.v7i2.63685

Yemane, D., Field, J.G., Leslie, R.W., 2005. Exploring the effects of fishing on fish assemblages using Abundance Biomass Comparison (ABC) curves. *ICES Journal of Marine Science.* 62, 374-379. https://doi.org/10.1016/j.icesjms.2005.01.009

Yuliana, E., Boer, M., Fahrudin, A., Kamal, M.M., Pardede, S.T., 2019. Using ecosystem approach indicators for assessing the ecological status of reef fisheries management in a marine protected area. *Biodiversitas.* 20, 1802–1810. https://doi.org/10.13057/biodiv/d200703

Zheng, Y., Liu, D., 2021. Research on marine pollution problems and solutions in China from the perspective of marine tourism. *J. Mar. Sci.* 3, 19–28. https://doi.org/10.30564/jms.v3i1.2599