

# Fish diversity in non-volcanic hydrothermal areas of the shallow sea waters of Kolono Bay, Southeast Sulawesi

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**Abstract.** Data on fish diversity in shallow marine hydrothermal areas of Indonesian waters are relatively limited. Underwater hydrothermal activity signifies active geothermal processes, where emitted fluids are known for their high temperatures. This study investigates the composition, relative abundance, and diversity of fish species in the non-volcanic hydrothermal zone of the shallow sea waters of Kolono Bay, Southeast Sulawesi. This research was conducted from March to August 2022, using a purposive sampling method. A total of 66 species were identified, belonging to 35 genera, 18 families, and 8 orders. The highest species composition was found in the families Lutjanidae and Scaridae at station I (17.40% and 17.39%, respectively), Lutjanidae at station II (20.60%), and Mullidae at Station III (21.74%). Bigeye snapper, *Lutjanus lutjanus* was the dominant species in the hydrothermal center (47.49%), while species from the genera *Chaetodon*, *Heniochus*, *Parachaetodon*, *Coradion*, *Inegocia*, and *Zanclus* were the least abundant (0.15% each). The diversity index ( $H' = 2.461-2.922$ ) indicated moderate diversity, with relatively good stability, productivity, and balanced ecosystem conditions. The uniformity index was high ( $E = 0.643-0.932$ ), while the dominance index was low ( $C = 0.064-0.239$ ), reflecting an even distribution of species with no clear dominance. The bigeye snapper, a species of reef fish, has demonstrated strong tolerance in both the central and border areas of these hydrothermal zones. This tolerance is evident from the higher abundance of individuals compared to other fish species from the same genus and habitat.

**Key Words:** bigeye snapper, diversity, hydrothermal, shallow seawater.

**Introduction.** Southeast Sulawesi Province is located at the convergence of three tectonic plates - the Indo-Australian, Pacific, and Eurasian plates - making it prone to earthquakes and tsunamis. These tectonic conditions result in frequent movements of the earth's crust, leading to the formation of several major faults, including a micro-fault in Southeast Sulawesi. This fault is associated with geothermal activity. Most of the geothermal potential on Sulawesi Island is linked to non-volcanic environments (Hamimu et al 2022). One of the shallow marine hot springs located in Kolono Bay, Southeast Sulawesi, at a depth of 29 meters below sea level, is suspected to be a non-volcanic hydrothermal system.

Underwater hydrothermal activity signifies active geothermal processes, where emitted fluids are known for their high temperatures. These geothermal fluids are typically characterized by low pH, negative redox potential, and elevated temperatures (Pichler et al 2019; Caramanna et al 2021). Gugliandolo et al (2015) reported a shallow marine hydrothermal area in a saltwater lake on the Eolian Islands, Italy, where the emitted water had a high temperature of 94°C, was extremely saline, and rich in CO<sub>2</sub> and H<sub>2</sub>S. Similarly, Jaya et al (2021) described a non-volcanic geothermal manifestation in the form of hot springs in the Wawolesea and Toreo village, North Konawe Regency Indonesia, with in situ temperature that lies between 30.2 and 65.5°C. Organisms living in underwater hydrothermal areas are typically adapted to these extreme conditions, including high

temperatures, CO<sub>2</sub>, H<sub>2</sub>S, and heavy metals, which are commonly released by geothermal activity (Turner et al 2016).

Hydrothermal areas, both in shallow and deep seas, harbor biodiversity that is crucial to study. However, most studies on hydrothermal areas have primarily concentrated on deep-sea environments, focusing on benthic microbes, benthic fauna, macrobiota, and fish (Alfaro-Lucas et al 2020; Zhou et al 2022; Hu et al 2023), with comparatively less research conducted in shallow waters. Within shallow marine hydrothermal areas, studies have primarily explored the diversity of benthic microbes (Rajasabapathy et al 2018; Arcadi et al 2023; Barosa et al 2023; Wang et al 2024), benthic fauna (Chen et al 2017; Wang et al 2022), and macrobiota (Chan et al 2016; Wu et al 2023). In contrast, research on fish diversity in these environments remains limited (Fernández et al 2014).

Biodiversity refers to the variation or variability of living organisms. Fish diversity is essential for ecosystem health, as it reflects habitat quality, species richness, and coral reef conditions (Kumar & Mina 2018). It also provides significant natural resources for humans, including food and livelihoods in the fisheries sector. Additionally, fish diversity plays a key role in aquatic resource management by contributing to the health and balance of aquatic ecosystems. Each fish species fulfills a unique ecological function, whether as a predator, detritus feeder, or plankton feeder, regulating populations and stabilizing the food chain. The loss of even a single species can disrupt ecosystem balance and lead to habitat changes (Banks-Leite et al 2020; Meinam et al 2023).

The hydrothermal area in the waters of Kolono Bay holds a diverse range of fish species that warrant further study. While some information on fish diversity in these waters has been reported by Asriyana et al (2020a, b) and Asriyana & Halili (2021), research specifically focused on fish diversity in hydrothermal areas remains unexplored. Therefore, this study serves as an initial step toward uncovering the fish diversity in shallow marine hydrothermal zones in Indonesia.

## Material and Method

**Research site.** This study was conducted in the shallow marine hydrothermal area of Kolono Bay, South Konawe Regency, Southeast Sulawesi (Figure 1) from March to August 2022. The research stations were selected using a purposive sampling method, which involved choosing sampling locations based on distinct water characteristics: one within the non-volcanic hydrothermal zone and the others outside of it. The sampling sites were divided into three stations, each spaced approximately 500 meters apart. The research stations were defined as follows:

- station I = located at coordinates 4°24'39.09622" S and 122°46'9.21387" E, this station is situated at the center of the non-volcanic hydrothermal area. The seabed is rocky (Figure 2), with a sandy clay substrate and a maximum water temperature of 34°C;
- station II = located at coordinates 4°24'39.09622" S and 122°46'9.21387" E, this station lies outside the hydrothermal area. It has a sandy clay substrate and a maximum water temperature of 28.9°C;
- station III = located at coordinates 4°24'39.09622" S and 122°46'9.21387" E, this station has a clay substrate, a maximum water temperature of 29.9°C, and is near a river flow.

**Fish collection.** A sampling frequency of four times was employed at each station, with two sampling events in the March-June 2022 period and two in the June-August 2022 period. Fish were collected using gill nets with six different mesh sizes (1, 1 1/2, 2, 2 1/2, 3, and 4 inches). Each net measured 40 meters in length and 2.5 meters in width. The fishing gear was operated during rising tides and retrieved as the water receded (±6 hours). Additionally, fish data were collected using the underwater visual census (UVC) method (Wilson et al 2018). The UVC method involved deploying a 50-meter transect parallel to the shoreline, with observations made within an imaginary line extending five meters to the left and right of the transect. Fish species were identified to the species level based on guidelines from Kuitert & Tonozuka (2001), White et al (2013), and Froese & Pauly (2023). Identification was performed underwater using an Olympus underwater camera.

The identified fish were then counted by species and grouped according to the sampling stations.

Water quality data collection was carried out twice a month with two repetitions, so that the total water quality data for the six months of research was 24 water quality data for each station. Water temperature and depth were measured using a dive computer (Shearwater brand), while salinity and dissolved oxygen (DO) levels were assessed using a water quality meter (AZ Instrument AZ-86031 brand). The pH of the water was determined using a pH meter (Hanna HI98107 brand), and water clarity was measured with a Secchi disk.

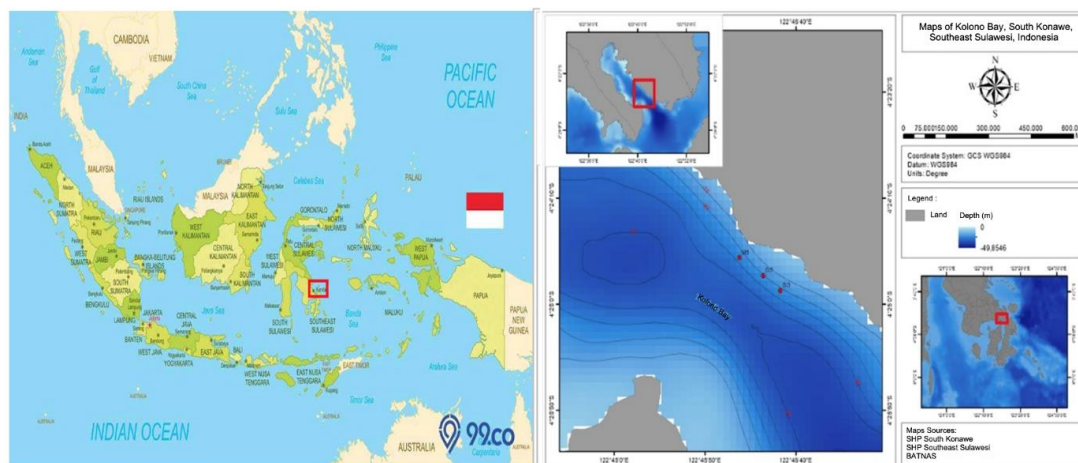


Figure 1. Research location.



Figure 2. Seabeds at station I.

**Calculations and statistical analysis.** The tabulated fish data were analyzed for species composition, relative abundance, and ecological indices according to the formulas provided by Brower et al (1997) and Asriyana et al (2020b). To determine whether there were differences in water quality parameter values between stations, a non-parametric statistical test, Kruskal-Wallis, was conducted with a significance level of 0.05 (Asriyana et al 2020a), using SPSS version 16.0 software. Species composition was calculated based on the number of species using the following formula:

$$P_i = \left(\frac{n_i}{N}\right) \times 100 \quad (1)$$

where:  $P_i$  = species composition (%) for species  $i$ , where  $i = 1, 2, 3, \dots, n$ ;  
 $n_i$  = number of individuals of species  $i$ , where  $i = 1, 2, 3, \dots, n$ ;  
 $N$  = total number of individuals of all species.

Fish species diversity was calculated using the Shannon & Wiener index (Brower et al 1997) :

$$H' = \sum \left[ \left( \frac{n_i}{N} \right) \ln \left( \frac{n_i}{N} \right) \right] \quad (2)$$

where:  $H'$  = diversity index;

$n_i$  = number of individuals of the  $i$ -th fish species;

$N$  = total number of individuals of all species.

The assessment criteria based on species diversity are as follows:

- if  $H' < 1$ , diversity is low, distribution is low, the number of ichthyofauna of each species is moderate, and community stability is low;

- if  $1 < H' < 3$ , diversity is moderate, distribution is moderate, the number of ichthyofauna of each species is moderate, and community stability is moderate;

- if  $H' > 3$ , diversity is high, distribution is high, the number of ichthyofauna of each species is high, and community stability is high.

The fish species uniformity index ( $E$ ) was calculated using the Shannon-Wiener modification formula (Brower et al 1997):

$$E = \frac{H'}{H_{max}} = \frac{H'}{\ln S} \quad (3)$$

where:  $E$  = uniformity index;

$H'$  = diversity index;

$H_{max} = \ln S$ ;

$S$  = number of fish species.

The species uniformity value ranges from 0 to 1. A smaller value (approaching zero) indicates low uniformity, suggesting that the distribution of individuals among species is uneven, with a tendency for one species to dominate the population. Conversely, a high uniformity value (approaching 1) indicates an even distribution of individuals among species, with no dominant species present.

Species dominance was calculated using the Simpson dominance index (Odum 1996):

$$C = - \sum \left( \frac{n_i}{N} \right)^2 \quad (4)$$

where:  $C$  = Simpson species dominance index;

$n_i$  = number of individuals of species  $i$ ;

$N$  = total number of individuals of all species.

The dominance index values range from 0 to 1:

- if  $C < 0.5$ , no species dominates;

- if  $0.5 < C < 1$ , there is a species that dominates.

## Results

**Composition and relative abundance of fish species.** During the study, the total fish catch amounted to 1,041 individuals, representing 66 species from 35 genera, 18 families, and 8 orders. Among these, *Lutjanus* was the genus with the largest number of species (9 species) compared to other genera found in the non-volcanic hydrothermal area of the shallow sea waters in Kolono Bay. The complete distribution of catches, categorized by order, family, genus, species, and relative abundance, is presented in Table 1.

The bigeye snapper *L. lutjanus* was the most abundant species, with a total of 398 individuals recorded during the study (Table 1). This species exhibited significant abundance at both stations I and II, with relative abundances of 47.49% and 32.08%, respectively. However, it was not observed at station III, which is situated near the river flow.

Table 1

Orders, families, genera, species, and relative abundance of fish species found in the non-volcanic hydrothermal area in the shallow sea waters of Kolono Bay

Order	Family	Genus	Species	Station			N (ind.)	Relative abundance (%)			
				1	2	3		St. 1	St. 2	St. 3	
Acanthuriformes	Acanthuridae	<i>Acanthurus</i>	<i>Acanthurus auranticavus</i>	+	+	+	27	1.78	4.17	4.00	
			<i>Acanthurus nigrofuscus</i>	+	+	+	10	0.89	0.83	1.60	
	<i>Acanthurus pyroferus</i>		+	-	-	5	0.74	-	-		
	<i>Acanthurus thompsoni</i>		+	+	+	11	0.74	1.25	2.40		
	Ctenochaetidae	<i>Ctenochaetus</i>	<i>Ctenochaetus binotatus</i>	+	-	-	6	0.89	-	-	
			<i>Ctenochaetus striatus</i>	+	-	-	6	0.89	-	-	
		Chaetodontidae	<i>Chaetodon</i>	<i>Chaetodon kleinii</i>	+	-	-	1	0.15	-	-
				<i>Coradion</i>	+	-	-	1	0.15	-	-
			<i>Heniochus</i>	<i>Heniochus acuminatus</i>	+	-	-	1	0.15	-	-
				<i>Heniochus chrysostomus</i>	+	-	-	1	0.15	-	-
	Siganidae	<i>Parachaetodon</i>	<i>Parachaetodon ocellatus</i>	+	+	-	3	0.15	0.83	-	
			<i>Siganus</i>	+	+	-	20	2.22	2.08	-	
		<i>Siganus</i>	<i>Siganus canaliculatus</i>	+	+	-	24	2.37	3.33	-	
			<i>Siganus javus</i>	+	+	-	14	1.78	0.83	-	
			<i>Siganus vulpinus</i>	+	+	-	7	0.74	0.83	-	
	Zanclidae	<i>Zanclus</i>	<i>Zanclus cornutus</i>	+	-	-	1	0.15	-	-	
	Aulopiformes	Synodontidae	<i>Saurida</i>	<i>Saurida micropectoralis</i>	-	+	+	8	-	0.83	4.80
Carangiformes	Carangidae	<i>Alectis</i>	<i>Alectis ciliaris</i>	-	-	+	2	-	-	1.60	
		<i>Atropus</i>	<i>Atropus armatus</i>	+	-	-	3	0.44	-	-	
		<i>Atule</i>	<i>Atule</i> sp.	-	+	-	2	-	0.83	-	
		<i>Decapterus</i>	<i>Decapterus macrosoma</i>	-	+	+	4	-	0.83	1.60	
		<i>Gnathanodon</i>	<i>Gnathanodon speciosus</i>	+	-	-	3	0.44	-	-	
		<i>Selaroides</i>	<i>Selaroides leptolepis</i>	+	+	+	90	5.62	20.00	3.20	
		<i>Turrum</i>	<i>Turrum coeruleopinnatum</i>	+	-	-	2	0.30	-	-	
	Sphyraenidae	<i>Sphyraena</i>	<i>Sphyraena forsteri</i>	-	+	-	4	-	1.67	-	
Rachycentridae	<i>Rachycentron</i>	<i>Rachycentron canadum</i>	-	-	+	2	-	-	1.60		
Dactylopteriformes	Dactylopteridae	<i>Dactyloptena</i>	<i>Dactyloptena orientalis</i>	-	+	-	1	-	0.42	-	
Eupercaria	Caesionidae	<i>Caesio</i>	<i>Caesio cunning</i>	+	-	+	25	2.22	-	8.00	
			<i>Caesio teres</i>	-	-	+	15	-	-	12.00	
		<i>Pterocaesio</i>	<i>Pterocaesio pisang</i>	+	-	+	35	2.96	-	12.00	
			<i>Pterocaesio tile</i>	+	-	-	15	2.22	-	-	
	Gerreidae	<i>Gerres</i>	<i>Gerres oyena</i>	-	+	+	8	-	0.83	4.80	
	Lutjanidae	<i>Lutjanus</i>	<i>Lutjanus argentimaculatus</i>	+	+	+	61	5.62	6.25	6.40	

			<i>Lutjanus biguttatus</i>	+	+	-	13	1.63	0.83	-
			<i>Lutjanus bouton</i>	-	+	-	7	-	2.92	-
			<i>Lutjanus carponotatus</i>	+	+	+	23	2.22	1.25	4.00
			<i>Lutjanus fulvus</i>	+	+	-	20	2.22	2.08	-
			<i>Lutjanus goldiei</i>	+	+	-	12	1.48	0.83	-
			<i>Lutjanus kasmira</i>	+	-	-	10	1.48	-	-
			<i>Lutjanus lutjanus</i>	+	+	-	398	47.49	32.08	-
			<i>Lutjanus madras</i>	+	-	-	6	0.89	-	-
	Nemipteridae	<i>Nemipterus</i>	<i>Nemipterus furcosus</i>	+	+	-	7	0.59	1.25	-
			<i>Nemipterus hexodon</i>	-	+	+	6	-	0.83	3.20
		<i>Scolopsis</i>	<i>Scolopsis aurata</i>	-	-	+	4	-	-	3.20
			<i>Scolopsis taenioptera</i>	-	+	+	17	-	3.35	7.20
	Scaridae	<i>Chlorurus</i>	<i>Chlorurus bleekeri</i>	+	-	-	3	0.44	-	-
			<i>Chlorurus sordidus</i>	+	-	-	3	0.44	-	-
		<i>Hipposcarus</i>	<i>Hipposcarus longiceps</i>	+	-	-	4	0.59	-	-
		<i>Scarus</i>	<i>Scarus dimidiatus</i>	+	-	-	4	0.59	-	-
			<i>Scarus ghobban</i>	+	-	-	2	0.30	-	-
			<i>Scarus rivulatus</i>	+	-	-	15	2.22	-	-
			<i>Scarus scaber</i>	+	-	-	4	0.59	-	-
			<i>Scarus tricolor</i>	+	-	-	7	1.04	-	-
Mulliformes	Mullidae	<i>Parupeneus</i>	<i>Parupeneus barberinus</i>	-	-	+	8	-	0.83	4.80
			<i>Parupeneus heptacantha</i>	-	-	+	1	-	-	0.80
			<i>Parupeneus indicus</i>	-	+	+	7	-	1.67	2.40
			<i>Parupeneus multifasciatus</i>	-	+	+	3	-	0.42	1.60
		<i>Upeneus</i>	<i>Upeneus asymmetricus</i>	-	+	+	6	-	0.83	3.20
Perciformes	Epinephelidae	<i>Cephalopholis</i>	<i>Cephalopholis argus</i>	+	+	-	4	0.40	0.42	-
			<i>Cephalopholis boenak</i>	+	+	-	7	0.59	1.25	-
		<i>Ephinephelus</i>	<i>Ephinephelus merra</i>	+	+	-	3	0.30	0.42	-
		<i>Plectropomus</i>	<i>Plectropomus leopardus</i>	+	+	-	5	0.44	0.83	-
	Platycephalidae	<i>Inegocia</i>	<i>Inegocia japonica</i>	+	-	-	1	0.15	-	-
Pleuronectiformes	Paralichthyidae	<i>Pseudorhombus</i>	<i>Pseudorhombus arsius</i>	-	+	+	9	-	0.85	5.60
			<i>Pseudorhombus elevatus</i>	-	+	-	3	-	1.25	-
Sum = 8	18	35	66	46	34	23	1041	100	100	100

Notes: N = sample; St. = station; + = available; - = not available.

The composition of fish families found in the non-volcanic hydrothermal area of the shallow sea waters of Kolono Bay is illustrated in Figure 3. The species composition varies between stations. At station I, the Lutjanidae and Scaridae families have the highest species composition, 17.40% and 17.39%, respectively. Conversely, the Zanclidae and Platycephalidae families exhibit the lowest species composition at 2.17%. At station II, the Lutjanidae family again dominated with the highest species composition at 20.60%. In contrast, the Chaetodontidae, Sphyraenidae, Dactylopteridae, and Synodontidae families each have the lowest species composition at 2.94%. At station III, the Mullidae family leads with a composition of 21.74%, while the Rachycentridae, Gerreidae, Paralichthyidae, and Synodontidae families each represent the lowest composition at 4.35%.

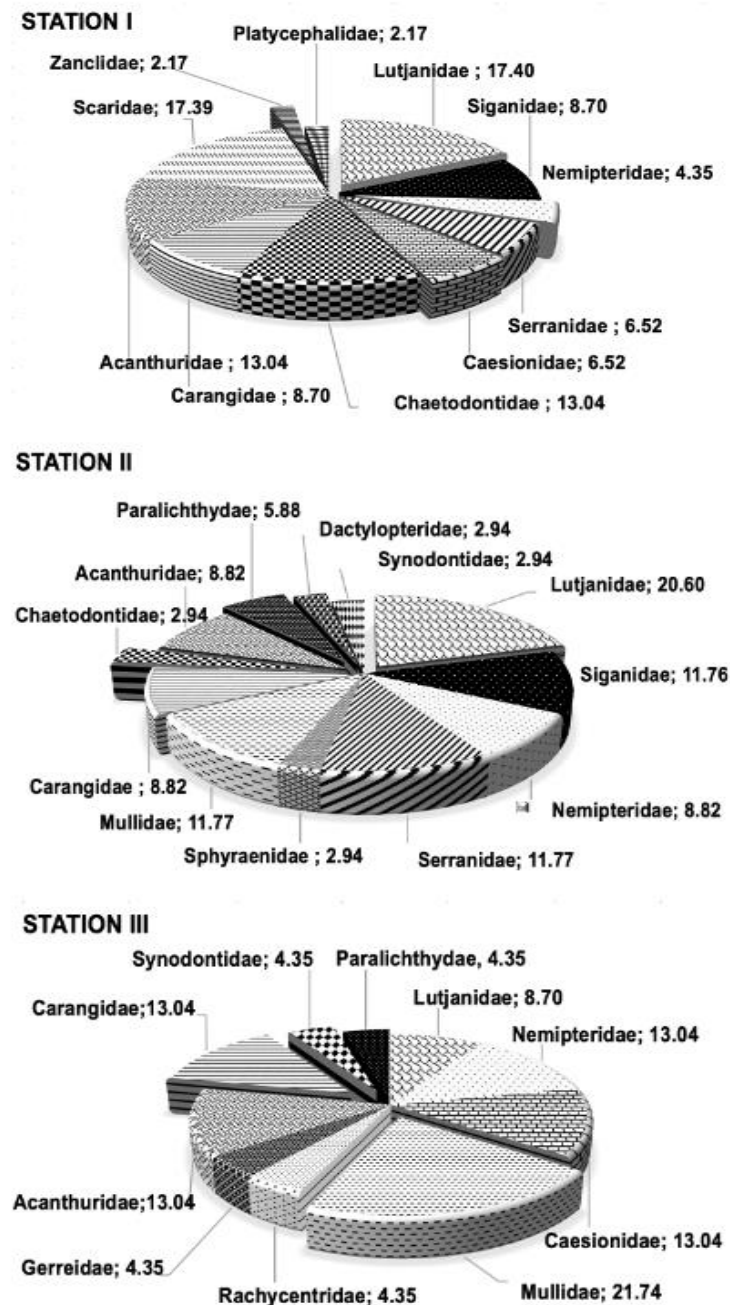


Figure 3. Composition of fish species at each station in the non-volcanic shallow sea hydrothermal area of Kolono Bay.

**Ecological indices.** The ecological indices, including diversity, uniformity, and dominance, are presented in Table 2. The values of these indices vary spatially. The diversity of fish species in the non-volcanic hydrothermal area of the shallow sea waters of Kolono Bay is classified as moderate ( $1 < H' < 3$ ). The population distribution is relatively even ( $E \approx 1$ ), and no single species dominates the area ( $C < 0.5$ ).

Table 2  
Index values of diversity, uniformity, and dominance of fish species in the non-volcanic hydrothermal area of the shallow sea waters of Kolono Bay, Southeast Sulawesi

Community structure	Station		
	I	II	III
Number of species	46	34	23
Number of individuals	676	240	125
Diversity index (H')	2.461	2.584	2.922
Maximum H'	3.829	3.555	3.136
Uniformity (E)	0.643	0.727	0.932
Dominance (C)	0.239	0.155	0.064

**Water quality.** The range of water quality parameter values, including temperature, water depth, water clarity, salinity, and dissolved oxygen, and pH are presented in Table 3. The values for each parameter are relatively uniform between stations, except for the temperature and depth parameters, which exhibit a higher range of values compared to the other stations.

Table 3  
Water quality parameter values for March-August 2022 in the non-volcanic hydrothermal area of the shallow sea waters of Kolono Bay

Parameters	Station I			Station II			Station III		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
Temperature (°C)	30.9	34	32.45	28.9	29.7	29.3	28.4	29.9	29.15
Depth (m)	29	29	29	24.50	24.80	24.65	25	25	25
Water clarity (m)	10	10	10	9	12	10.5	7	8	8.5
Salinity (‰)	30.85	30.85	30.85	29.5	30.5	30	29.3	30	29.65
DO (mg L <sup>-1</sup> )	5.3	5.4	5.35	4.9	6.4	5.65	4.7	4.8	4.75
pH	6.99	7.99	7.49	7.33	8.1	7.71	7.13	8.1	7.61

$p > 0.05$  ( $\alpha$ : 5%, df: 2), the Kruskal Wallis Test

**Discussion.** The non-volcanic hydrothermal area in the shallow sea waters of Kolono Bay is home to 66 species of fish, belonging to 35 genera, 18 families, and 8 orders. This species diversity is lower than that observed in other regions, such as Kolono Bay, which has around 68 species from 24 families (Asriyana et al 2020b); the shallow seas of South Japan, with 70 species (Koeda et al 2021); but higher than the Lalowaru coast with 45 species from 27 families (Muhajirah et al 2017). The variation in species richness can primarily be attributed to the characteristics of non-volcanic hydrothermal areas. The fish species found in this region are adapted to higher temperature conditions compared to those in other waters (Table 3). Several studies have indicated that non-volcanic hydrothermal areas are characterized by low pH, negative redox potential, high temperatures, and elevated levels of CO<sub>2</sub>, H<sub>2</sub>S, and heavy metals (Turner et al 2016; Pichler et al 2019; Caramanna et al 2021; Jaya et al 2021).

The Lutjanidae and Scaridae families represent the two groups with the highest species composition at station I, accounting 17.40% and 17.39% respectively (Figure 3). Station I is characterized by rocky substrates (Figure 2), which serve as the preferred

habitat for both families. Lutjanidae comprises reef fish that inhabit rocky environments, slopes, steep drop-offs, and algal reefs in shallow waters. Some species within this family exhibit solitary or group behaviors during both juvenile and adult stages (Kuitert & Tonozuka 2001). Similarly, the Scaridae family, commonly known as parrotfish, inhabits rocky ecosystems. With their teeth resembling a parrot's beak, these fish feed on dead coral overgrown with algae and other plant matter. Species such as *S. ghobban* and *C. sordidus* occupy lagoon areas as juveniles but prefer lagoons, coral reefs, atolls, and steep coral slopes as adults, often transitioning from rubble to healthy corals (Gobalet 2018; Hoey & Bonaldo 2018; Gao et al 2023). According to Asriyana & Halili (2021), a high composition of fish species indicates varied habitat conditions and a greater number of species compared to other species. The lower representation of *C. kleinii*, *P. ocellatus*, *H. chrysostomus*, *H. diphreutes*, *H. acuminatus*, and *C. melanopus* from the Chaetodontidae family (butterflyfish) may be attributed to their close association with coral reefs, where they rely on coral polyps as their primary food source (Nurjirana & Burhanuddin 2017; Octavina et al 2021; Ulfah et al 2023). Since Station I does not comprise a coral reef ecosystem, the low diversity of these species is expected.

The Lutjanidae family at station II has a larger species composition compared to station I. Although station I has a rocky base resembling a coral reef area, the relatively high temperature conditions may make Lutjanidae prefer station II, which is located outside the non-volcanic hydrothermal area. This preference is reflected in the species composition of Lutjanidae at station II, which is higher at 20.60% compared to 17.40% at station I. Additionally, the difference in species composition percentages is influenced by the total number of species present at each station. Station I consisted of 46 species, a larger number than Station II, which comprised 34 species.

The highest species composition of fish at station III came from the Mullidae family (21.74%), with five species out of the total 23 species forming the fish community at this station. Station III is located near a river flow, which is the preferred habitat of Mullidae (White et al 2013). According to Asriyana & Halili (2021), the genus *Upeneus* from the Mullidae family typically inhabits sandy bottoms and is associated with brackish water. Several species are oceanodromous and capable of migrating through both sea and brackish waters. The number of Mullidae species found in this study area was smaller than in Kolono Bay, where 11 species were reported (Asriyana & Halili 2021). This difference is likely due to the relatively limited scope of this research compared to Asriyana & Halili's (2021) study, which covered a broader area of Kolono Bay, including a variety of habitats such as coral reefs, seagrass beds, mangroves, and river inflows. A more heterogeneous physical environment tends to support more complex communities, resulting in higher species diversity.

Bigeye snapper (*L. lutjanus*) has the highest relative abundance and is found only at stations I and II, but not at station III (Table 1). Similar to seven other species, *L. lutjanus* was absent from station III, except for *L. argentimaculatus* and *L. carponotatus*. Station I has a rocky bottom, resembling a coral reef habitat (Figure 2), which is ideal for *L. lutjanus*. According to Constante-Pérez et al (2022) and Martínez-Juárez et al (2024), fish from the Lutjanidae family inhabit shallow waters with rocky and coastal environments, as well as offshore areas. *L. lutjanus* can live in both large and small groups alongside other *Lutjanus* species, though it sometimes lives solitarily. Station II is the transition zone between *L. lutjanus*' preferred rocky habitat and areas influenced by river flow. *L. argentimaculatus* and *L. carponotatus* are adapted to estuarine waters and deeper reefs, preferring muddy environments characteristic of river basins (Kuitert & Tonozuka 2001; White et al 2013).

The diversity of fish species in the study area, as measured by the ecological index, falls within the moderate diversity category ( $1 < H' < 3$ ). However, the diversity index at station III is higher than at stations I and II, which are located in the central and border areas of the non-volcanic hydrothermal zone. Station III, an estuarine area where river and seawater mix, benefits from nutrient influx from the river, enriching its waters. Estuarine environments are typically highly productive, providing habitats for various fish species for shelter, feeding, and growth (Asriyana et al 2018). In addition to being productive, species diversity is influenced not only by the number of individuals and species

present in a community but also by how evenly these species are distributed, with no single species dominating. Moderate diversity suggests a relatively stable ecosystem, good productivity, and balanced ecological conditions (Protasov et al 2019; Wisnoski et al 2023). According to Roswell et al (2021) and Plaksina et al (2023), species diversity tends to be low in communities with few species and a dominant one, whereas diversity is higher in communities with many species and no single species dominating.

The uniformity index in this water area is relatively high (0.643-0.932), following the same trend as the diversity index. Uniformity values close to 0 indicate the presence of dominant species in the ecosystem, while values approaching 1 suggest a balanced community with an even distribution of individuals (Krebs 1989). The moderate-to-high diversity and uniformity indices are inversely related to the low dominance index values (0.064-0.239) (Table 3). This suggests that no single fish species dominates the area, as a lower dominance index reflects a more evenly spread pattern of species dominance. The dominance index in the central non-volcanic hydrothermal zone is higher compared to the border and outer areas (Table 2). This indicates that certain species in the hydrothermal zone (Table 1) are better adapted to the specific habitat conditions, such as elevated water temperatures. The bigeye snapper, in particular, has the highest number of individuals compared to other species, especially in the central and border regions of the non-volcanic hydrothermal area.

Ecologically, shallow water habitats and coastal areas are considered highly productive (McLean et al 2019), with temperature being a critical factor influencing environmental stress, which can significantly impact organism survival (Vinagre et al 2018; Giomi et al 2019). Although water quality parameters between stations show no significant differences (Table 3), the temperature at station I is notably higher than at other stations. This elevated temperature is due to the station's location in the center of the shallow sea hydrothermal area, where an active geothermal source emits hot water through rock fractures. According to Van Dover (2014), hydrothermal areas are localized regions of the seabed where seawater, having undergone geothermal heating and chemical changes, emerges either diffusely or in concentrated flows. Several studies have reported that hydrothermal regions can have significantly elevated water temperatures. Gugliandolo et al (2015) reported high concentrations of CO<sub>2</sub> and H<sub>2</sub>S, along with emissions reaching temperatures of 94°C, in a shallow marine hydrothermal area of the Eolian Islands saltwater lake in Italy. Similarly, Rizzo et al (2022) reported high-temperature emissions (120°C) from a shallow marine hydrothermal area in saltwater Levante Bay.

Several studies have demonstrated that certain reef fish species exhibit a relatively high tolerance to elevated temperatures. Edwarsyah et al (2021) reported the distribution of several reef fish species around Simelue Island, Aceh, at maximum temperatures of 34.5°C for *Paracanthurus hepatus*, 34.61°C for *Amphiprion polymnus* and *Epinephelus fuscoguttatus*, and up to 35.61°C for *L. argentimaculatus*. This suggests that several reef fish species can adapt to temperatures as high as 34.61°C. Similarly, Mora & Ospina (2001) reported that the maximum temperature tolerance limit of 15 reef fish species around Gorgona Island, in the Tropical Eastern Pacific zone, showed that all species studied could tolerate temperatures up to 40°C. These findings indicate that certain reef fish species can survive temperature increases, such as those resulting from global warming, within a specific time frame. Similarly, it was reported by Valente et al (2023) that temperature plays a major role in influencing abundance of species with warm-water affinities, and that there are more thermophilic species in areas with higher seawater temperatures. One example of environments where thermophilic species are found are hot springs, hydrothermal vents, and other geothermal areas.

**Conclusions.** The diversity and uniformity of fish communities in the non-volcanic hydrothermal areas of Kolono Bay fall within the medium to high categories, accompanied by low dominance levels. The bigeye snapper (*L. lutjanus*), a species of reef fish, has demonstrated strong tolerance in both the central and border areas of these hydrothermal zones. This tolerance is evident from the higher abundance of individuals compared to other fish species from the same genus and habitat. Furthermore, the water quality parameters in this area are mostly within the tolerance limits of marine biota, although the

high temperature in the central hydrothermal area is a concern. These findings open up opportunities for further research on the adaptation of biota to extreme conditions, biodiversity conservation, and the development of blue economy potentials.

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