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# Biomonitoring of the Application of Monoculture and Integrated Multi-Trophic Aquaculture (IMTA) Using Macrobenthic Structures at Tembelas Island, Kepulauan Riau Province, Indonesia

Sapto P. Putro <sup>1,2,\*</sup> , Jeanny Sharani <sup>2</sup>, Widowati <sup>3</sup>, Satriyo Adhy <sup>4</sup> and Suryono <sup>5</sup>

<sup>1</sup> Center of Marine Ecology and Biomonitoring for Sustainable Aquaculture, Diponegoro University, Semarang, Central Java 50275, Indonesia

<sup>2</sup> Department of Biology, Faculty of Science and Mathematics, Diponegoro University, Semarang, Central Java 50275, Indonesia; jeanshrn@gmail.com

<sup>3</sup> Department of Mathematics, Faculty of Science and Mathematics, Diponegoro University, Semarang, Central Java 50275, Indonesia; wiwied\_mathundip@yahoo.com

<sup>4</sup> Department of Informatics, Faculty of Science and Mathematics, Diponegoro University, Semarang, Central Java 50275, Indonesia; satriyoadhy@gmail.com

<sup>5</sup> Department of Physics, Faculty of Science and Mathematics, Diponegoro University, Semarang, Central Java 50275, Indonesia; suryonosur@gmail.com

\* Correspondence: saptoputro@gmail.com; Tel.: +62-81390166126

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**Abstract:** Sustainable aquaculture needs to be considered when it comes to the utilization of water resources. The aim of this study was to apply biomonitoring using macrobenthic structures on both spatial and temporal applications of monoculture and integrated multi-trophic aquaculture (IMTA) at Tembelas Island, Kepulauan Riau Province, Indonesia. Samples of sediment were taken from three fish farm locations, namely from an IMTA site, a monoculture site, and a reference site. Macrobenthic organisms obtained through rinsing, sieving, and sorting were then identified under a stereo-microscope. Diversity of the macrobenthic assemblages was analyzed with a Shannon-Wiener index ( $H'$ ). Equitability was expressed through Pielou's evenness index. Finally, Bray-Curtis' non-metric multi-dimensional scaling (NMDS) was used for similarities derived from  $\log(X+1)$  transformed macrobenthic abundance to provide a visual representation of differences in their structure between sites over time. Results showed polychaetes exhibited differences in both variation and abundance of genera between the farm and reference site. The assemblage of macrobenthos at the IMTA site consisted of 9 genera of gastropods, 3 genera of bivalves, 5 genera of polychaetes, and 2 genera of crustaceans. At the monoculture site, 12 genera of gastropods, 4 genera of bivalves, 8 genera of polychaetes, 1 genera of crustaceans, and 1 genera of ophiuroid were observed. A relatively high abundance was observed at the reference site, with 27 genera of gastropods, 11 genera of bivalves, 3 genera of polychaetes, and 1 genera of crustacean. The favorable water conditions and possible absence of waste input from aquaculture resulting in a more suitable habitat for macrobenthic life may explain this relative abundance. Some of them were recognised as opportunistic taxa, i.e., *Capitella* sp., *Heteromastus* sp., and *Lumbrinereis* sp. Based on the diversity and evenness indices and the MNDS ordination, it can be concluded that the application of IMTA systems results in a suppressed or reduced potential impact on environmental disturbance due to aquacultural activities.

**Keywords:** sustainable aquaculture; IMTA; macrobenthic assemblages; polychaetes; environmental disturbance

## 1. Introduction

In various countries the aquaculture sector has grown tremendously over the last two decades, in line with the increasing global demand for high protein foods. According to ref. [1], global fish production is estimated to have reached about 179 million tonnes in 2018, of which 82 million tonnes came from aquaculture production. Among the major producing countries are China, India, Indonesia, Vietnam, Bangladesh, Egypt, Norway, and Chile. All have consolidated their share in regional or world production to varying degrees over the past two decades. Unfortunately, the percentage of fish stocks that are within biologically sustainable levels have decreased from 90% in 1974 to 65.8% in 2017. Furthermore, 85% of the world's marine fishery resources have been overexploited, with some species having been driven to near extinction. Meanwhile, the demand for fish protein for human consumption continues to rise. With the world's human population expected to reach 9 billion by 2050, the demand for protein sources will continue to exceed wild fishery production. Furthermore, current protein demand for the 7.3 billion humans on earth is approximately 202 million tonnes. Aquaculture's strength lies in its potential for sustainability. To keep up with growing demand and to prevent depletion of fish stocks, aquaculture must continue to become more sustainable [2]. Even though it is considerably more sustainable than wild fishery, continuous developments of balanced and sustainable techniques for improved aquaculture production must be achieved [2,3]. The sustainability of currently deployed farming practices in maintaining the carrying capacity of water ecosystems has become a primary concern. Ref. [4] emphasized serious concerns for the pollution of water surrounding aquacultural farms, as it is overdependent on a supply of fishmeal and fish oil, the use of soy, and chemicals in aquaculture feed and is linked to habitat destruction.

Problems in Indonesia's aquaculture sector generally surround suboptimal support facilities and infrastructure for aquaculture and insufficient application of good aquaculture practices among fish cultivators, largely due to a lack of technical mastery [5]. Various efforts have been made by the central and regional governments and by the private sector over the last two decades by increasing production capacity by means of extensification and intensification [6]. Furthermore, the private sector has been encouraged by the government to form fishery associations. In line with these commitments, the government has established semi-governmental organizations in which government staff and stakeholders are full members. The Tuna Committee, the Shrimp Committee, and the Seaweed Committee, headed by an independent chairman and with members representing both the government and the private sector, were formed in 2004 [6]. The primary challenge that the Indonesian aquaculture sector faces today is the balancing of intensive but productive aquaculture practices to keep up with the growing demand, with the carrying capacity of the local environments. Sustainable aquaculture is a prospect that should always be considered when utilizing coastal resources [5]. Ref. [7] reported environmental degradation over the last two decades caused by fish farming practices in Thailand, such as habitat destruction, water pollution, and negative ecological effects. Environmentally friendly aquaculture farming is expected to be the basis of viable long-term solutions. Some other factors responsible for the decline of economic value of water ecosystems may include increased use of aquatic resources and mismanagement due to conflicts of interest among users of water areas. A suitable conceptual framework for environmental protection and sustainable development of the economies of the water ecosystem is needed [8].

To achieve this, innovative monoculture and polyculture practices such as integrated multi-trophic aquaculture (IMTA) may be applied. IMTA is an aquaculture system that allows for simultaneous farming of multiple species of organisms with a mutualistic ecologic relationship in the food chain, linked by nutrient and energy transfer through the water ecosystem. By utilizing IMTA, productivity may be increased without the need to expand surface area utilization [3,4]. However, the potential impact of this farming method requires further assessment in line with concerns over the balance between productivity and sustainability. The accumulation of organic-rich sediments underneath IMTA facilities and the consequent depletion of oxygen in the sediment pore water may result in changes in *infaunal* assemblages. Ref. [9] reported on the substantial accumulation of organic matter on sediment

underneath fish farms in the Mediterranean Sea. Furthermore, the recovery process of the microbenthic community may depend on environmental conditions, whereas modifications to the structure of benthic communities persists over a longer time period, negatively impacting benthic ecosystem functioning [10].

The depletion of oxygen is primarily a result of an increased consumption of aerobic bacteria and other organisms that degrade organic wastes. The subsequent waste may result in qualitative and quantitative changes in the benthic environment. Furthermore, ref. [2] emphasized that the simultaneous use of the aquatic area for both aquaculture and other industrial activities simultaneously may lead to environmental disturbances. The application of biomonitoring is therefore necessary to assess the level of disturbance surrounding farmed areas, both spatially and temporally [11]. One such monitor is the structure of macrobenthos. These are organisms that are considerably sensitive to environmental disturbances, particularly those caused by organic enrichment. They exhibit a wide range of tolerance or sensitivity to different stressors [1], are relatively immobile and sedentary throughout the whole or part of their life in sedimentary habitats [11], and have already been widely used as an indicator for environmental assessments [12]. Marine soft-bottom macrozoobenthic communities have the inherent ability of reflecting their environment's circumstances. However, some studies have shown the importance of physical abiotic factors as the main drivers of the spatial patterns of macrobenthic species distribution, i.e., temperature and salinity gradients of water [13], the availability of food, dissolved organic particles, salinity, and sediment grain sizes [14]. Spatially, they are mainly influenced by sediment characteristics, such as organic matter and grain size [15].

## 2. Materials and Methods

### 2.1. Study Area

This research was conducted at the coastal area of Tembelas Island, Strait Malaka, Karimun Regency of Kepulauan Riau Province, between 103°17'30" E–103°18'15" E and 0°58'45" N–0°59'15" N. This study covered three different sampling locations, namely where the IMTA farming method was applied (IMTA Site), a reference site situated roughly 1 km from the IMTA site (Reference Site), and a monoculture site situated roughly 3 km from the IMTA site (Monoculture Site) (Figure 1). The farmed biotas included Asian sea bass (*Lates calcarifer*), tiger grouper (*Epinephelus fuscoguttatus*), and pomfret star (*Trachinotus blochii*) with 25 fish/m<sup>3</sup> in density for each species; 50 brackets of 250 g seaweed (*Eucheuma cottonii*) were also farmed with a transversal line system surrounding the bench of the 86.16 m<sup>3</sup> IMTA cage. Other biotas, i.e., sea cucumbers (*Stichopus hermannii*) and Indo-Pacific starfish (*Linckia laevigata*) were included with as many as 20 individuals for each species in the 6 m-diameter rounded IMTA cage system. Pellet was administered during the growing period with a protein content of 25–30% and as much as 5–10% mm/day. Meanwhile, Asian sea bass (*Lates calcarifer*) was farmed in a monoculture cage, which was roughly 3 km from the IMTA site.



**Figure 1.** The three sampling locations at the coastal area of Tembelas Island, Strait Malaka, Kepulauan Riau Province, Indonesia.

## 2.2. Sediment Collection

Sediment samples were gathered from the three sampling locations using an Ekman grab. They were stored in 2 L plastic jars with 10% formalin added. The samples were then sieved through a 1.0 mm mesh. Macrobenthic organisms obtained through rinsing, sieving, and sorting were then identified under a stereo-microscope. Sorted specimen were based on a group of taxa (genera) belonging to each station before enumeration. The benthic organisms were subsequently preserved in 70% ethanol for further analyses. Enumeration and identification of benthic organisms was carried out at the genus taxonomic level. The number of taxa (S) was used to compare taxon richness between sites and time frames.

## 2.3. Indices and Multivariate Analysis

The diversity of the macrobenthic assemblages was analyzed using the Shannon-Wiener index ( $H'$ ), after  $\log(X+1)$  transformation. Pielou's evenness index was used to express equitability. All indices were presented graphically as plots of means and with 95% confidence intervals within sampling times [1,11]. Bray-Curtis' non-metric multi-dimensional scaling (NMDS) of similarities was used

to provide a visual representation of differences between sites over time. Metric multi-dimensional scaling (MDS) plots derived from log(X+1) transformed macrobenthic abundance for each sampling period. The initial analysis incorporates all sites at all times to observe any tendency for separation between the farmed and reference sites. A dash-circle was used on the ordination to indicate any tendency of grouping of the stations between locations and sampling time [12,16].

### 3. Results

#### 3.1. Macrobenthic Structure: Spatial and Temporal

The monoculture site exhibited a higher abundance of macrobenthic taxa than the IMTA site, as is demonstrated in Table 1. The assemblage of macrobenthos at the monoculture site consisted of 12 genera of gastropods, 4 genera of bivalves, 8 genera of polychaetes, 1 genera of crustaceans, and 1 genera of ophiuroid. A relatively high abundance was observed at the reference site with 27 genera of gastropods, 11 genera of bivalves, 3 genera of polychaetes, and 1 genera of crustacean. At the IMTA site we observed 9 genera of gastropods, 3 genera of bivalves, 5 genera of polychaetes, and 2 genera of crustaceans.

**Table 1.** Spatial and temporal macrobenthic assemblages at three sampling locations at Tembelas Island, Kepulauan Riau Province, Indonesia.

No.	Class	Family	Genus	ABUNDANCE (ind./grab)					
				Sampling I			Sampling II		
				I	II	III	I	II	III
1.	Gastropoda	Ellobiidae	<i>Ellobium</i> sp.	2	4	36	6	0	11
		Columbellidae	<i>Costoanachis</i> sp.	6	24	20	0	0	0
			<i>Parvanachis</i> sp.	4	0	3	0	2	0
			<i>Mitrella</i> sp.	4	0	0	0	4	0
			<i>Pyrene</i> sp.	2	6	0	2	2	0
		Naticidae	<i>Naticarius</i> sp.	4	0	1	0	0	0
		Nassariidae	<i>Nassarius</i> sp.	4	18	48	7	6	6
		Terebridae	<i>Terebra</i> sp.	0	0	0	1	4	0
		Pyramidellidae	<i>Turbonilla</i> sp.	0	0	0	1	6	0
			<i>Boonea</i> sp.	0	0	2	0	0	0
			<i>Odostomia</i> sp.	0	0	2	0	0	0
		Cerithiidae	<i>Clypeomorus</i> sp.	0	4	0	0	0	0
			<i>Cerithium</i> sp.	0	0	0	0	2	0
		Architectonicidae	<i>Architectonica</i> sp.	0	0	0	0	2	0
		Buccinidae	<i>Neptunea</i> sp.	0	4	0	0	0	0
		Muricidae	<i>Ocinebrina</i> sp.	0	0	2	0	0	0
		Ovulidae	<i>Pellissimnia</i> sp.	0	0	1	0	0	0
		Fissurellidae	<i>Tugali</i> sp.	0	0	0	0	0	1
		Mangeliidae	<i>Agathotoma</i> sp.	0	0	2	0	0	0
			<i>Pyrgocythara</i> sp.	0	0	2	0	0	2
		Epitoniidae	<i>Epitonium</i> sp.	0	0	8	0	0	0
		Volutidae	<i>Ericusa</i> sp.	0	0	7	0	0	0
		Muricidae	<i>Murex</i> sp.	0	0	1	0	0	0
			<i>Eupleura</i> sp.	0	0	2	0	0	0
			<i>Ocinebrina</i> sp.	0	0	2	0	0	0
		Marginellidae	<i>Prunum</i> sp.	0	0	5	0	0	0
		Turridae	<i>Glyphoturris</i> sp.	0	0	3	0	0	0
		Babyloniidae	<i>Babylonia</i> sp.	0	0	4	0	0	0
		Mitridae	<i>Mitra</i> sp.	0	0	1	0	0	0
		Skeneidae	<i>Leucorhynchia</i> sp.	0	0	5	0	0	0
		Turbinidae	<i>Turbo</i> sp.	0	0	1	0	0	0
		Trochidae	<i>Austrocochlea</i> sp.	0	0	2	0	0	0
<i>Clanculus</i> sp.	0		0	1	0	0	0		
Batillariidae	<i>Batillaria</i> sp.	0	0	3	0	0	2		
Assimineidae	<i>Assiminea</i> sp.	0	0	11	0	0	0		

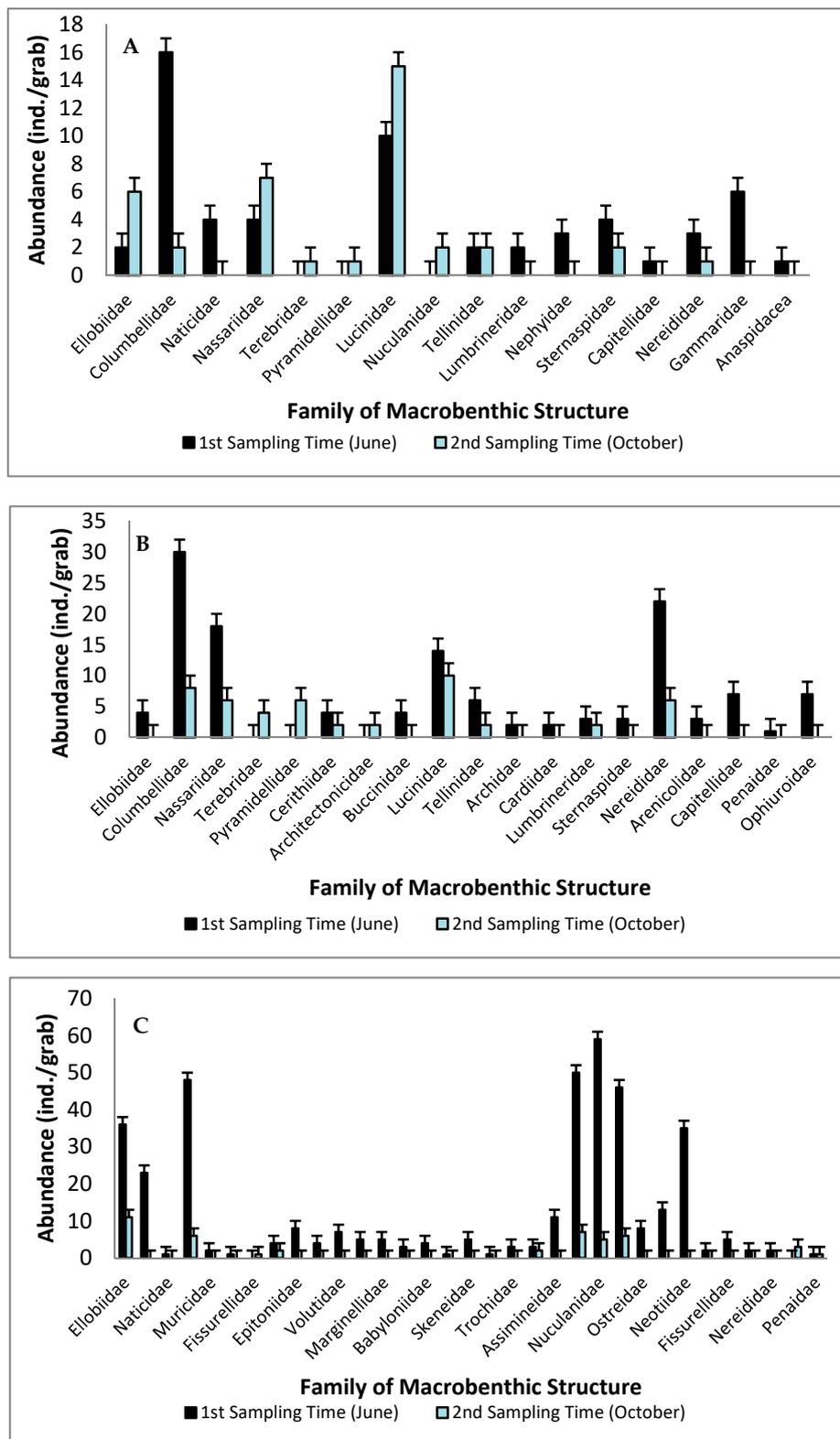
Table 1. Cont.

No.	Class	Family	Genus	ABUNDANCE (ind./grab)						
				Sampling I			Sampling II			
				I	II	III	I	II	III	
2.	Bivalvia	Lucinidae	<i>Anodontia</i> sp.	10	14	14	15	10	7	
			<i>Lucina</i> sp.	0	0	36	0	0	0	
		Nuculanidae	<i>Nuculana</i> sp.	0	0	59	2	0	5	
			Tellinidae	<i>Tellina</i> sp.	2	6	0	2	2	0
		Archidae	<i>Anadara</i> sp.	0	2	30	0	0	0	
			<i>Arca</i> sp.	0	0	16	0	0	6	
		Cardiidae	<i>Fulvia</i> sp.	0	2	0	0	0	0	
		Ostreidae	<i>Ostrea</i> sp.	0	0	8	0	0	0	
		Nacellidae	<i>Cellana</i> sp.	0	0	13	0	0	2	
		Neotiidae	<i>Arcopsis</i> sp.	0	0	35	0	0	0	
		Crassatellidae	<i>Crassatella</i> sp.	0	0	2	0	0	0	
		Fissurellidae	<i>Diodora</i> sp.	0	0	4	0	0	0	
			<i>Emarginula</i> sp.	0	0	1	0	0	0	
			3.	Polychaeta	Lumbrineridae	<i>Lumbrineris</i> sp.	2	3	0	0
Nephtyidae	<i>Nephtys</i> sp.				3	0	2	0	0	0
Sternaspidae	<i>Sternaspis</i> sp.	4	3	0	2	0	0			
	Nereididae	<i>Nereis</i> sp.	3	18	0	1	6	0		
Arenicolidae	<i>Namanereis</i> sp.	0	4	2	0	0	0			
	<i>Arenicolides</i> sp.	0	3	0	0	0	0			
Capitellidae	<i>Heteromastus</i> sp.	0	2	0	0	0	0			
	<i>Capitella</i> sp.	1	4	0	0	0	0			
	<i>Mediomastus</i> sp.	0	1	0	0	0	3			
4.	Crustacea	Penaidae	<i>Penaeus</i> sp.	0	1	1	0	0	1	
		Gammaridae	<i>Talorchestia</i> sp.	6	0	0	0	0	0	
		Anaspidae	<i>Anaspides</i> sp.	1	0	0	0	0	0	
5.	Ophiuroidea	Ophiuridae	<i>Ophioplocus</i> sp.	0	7	0	0	0	0	
		Total abundance (A)		58	139	398	39	48	46	
	Number of genera (s)		15	19	40	9	12	11		
	Diversity index (H')		2.53	2.63	2.94	1.78	2.31	2.15		
	Evenness index (e)		0.94	0.90	0.80	0.81	0.93	0.90		
	Dominance index (C)		0.09	0.09	0.03	0.23	0.11	0.14		

Note: Location I = integrated multi-trophic aquaculture (IMTA) site. Location II = monoculture site. Location III = reference site.

### 3.2. The Dominant Taxa of Macrobenthic Assemblages

The macrobenthic structures at both the IMTA and the monoculture sampling site were dominated by mollusks and polychaetes, whereas crustaceans and ophiuroids were found at average to below average numbers. The dominant taxa of mollusks at all three study locations were *Nassarius* sp. and *Anodontia* sp., both spread fairly evenly between the sampling stations. The dominant macrobenthic organism at both the IMTA and monoculture farm was *Tellina* sp. (Table 1; Figure 2). Among the polychaetes we observed a variance in number of taxa and abundance, especially when comparing the IMTA (5 genera) and monoculture (8 genera) sites with the reference site (2 genera). Some of these genera are opportunistic taxa, namely *Capitella* sp., *Heteromastus* sp., and *Lumbrineris* sp. [16,17]. Furthermore, polychaetes genera that were found at both the IMTA and the monoculture site were *Capitella* sp., *Lumbrineris* sp., *Sternaspis* sp., and *Nereis* sp.



**Figure 2.** The structure of macrobenthos at (A) IMTA, (B) monoculture, and (C) reference site in different sampling time ( $\pm$ SD).

### 3.3. The Macrobenthic Assemblages Expressed in Indices

The diversity, evenness, and dominance indices for the IMTA, monoculture, and reference site are presented in Table 2. The diversity index ( $H'$ ) for the three study sites shows only slight variance.

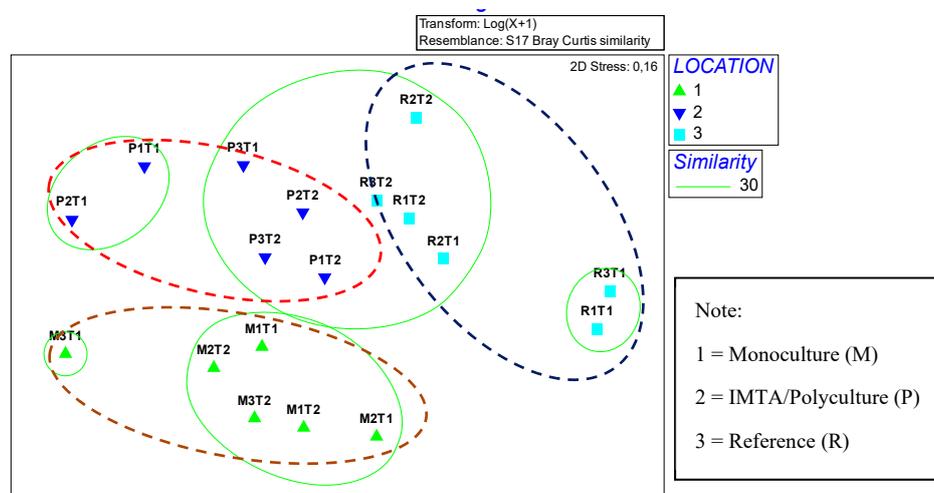
However, they exhibited lower at the second sampling times, compared to the first sampling time for all study sites. Evenness expressed using Pielou’s index showed only slight difference, valued between 0.80 and 0.94, whereas the dominance of some taxa (expressed by genus), shown by a higher rating for C Simpson index, is slightly greater at the second sampling time than at the first sampling time, although no significant difference was recorded between study sites.

**Table 2.** The values of diversity, evenness, and dominance indices, comparing the monoculture, IMTA, and reference site.

Sampling Location	Diversity Index (H')	Pielou Index (J')	Dominance Index (C)
IMTA I	2.53	0.94	0.09
IMTA II	1.78	0.81	0.23
Monoculture I	2.63	0.90	0.09
Monoculture II	2.31	0.93	0.11
Reference I	2.94	0.80	0.03
Reference II	2.15	0.90	0.14

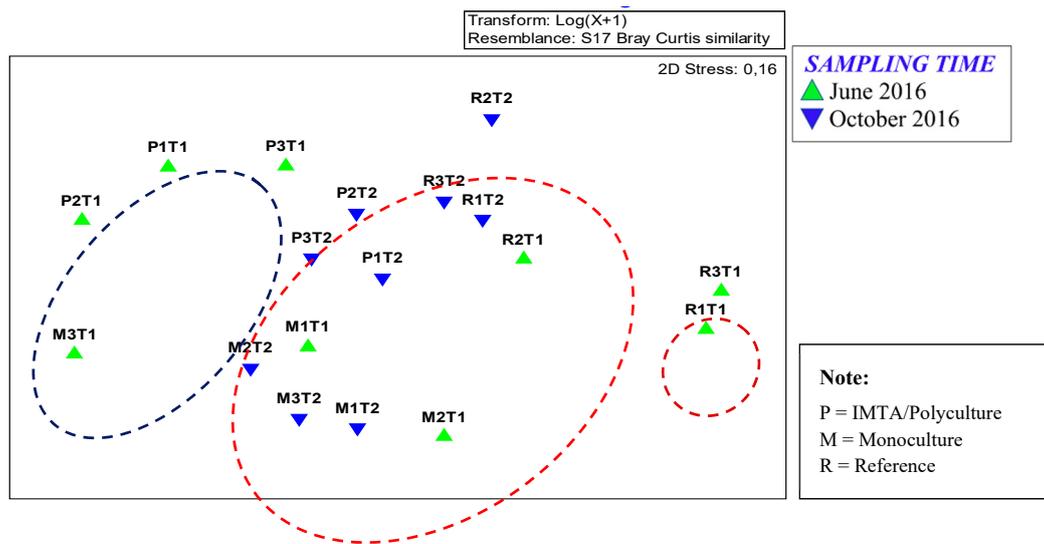
### 3.4. Macrobenthic Assemblages Expressed with the NMDS Graphical Method

Results from 2D ordination of nonmetric multidimensional scaling (NMDS) indicate a tendency of the sampling station ordinates to scatter, based on a 30% similarity value. However, the sampling stations also showed a tendency of forming clusters based around the different farm types. The clustering around the IMTA site, the monoculture site, and the reference site are illustrated in Figure 3.



**Figure 3.** The 2D ordination of nonmetric multidimensional scaling (NMDS), indicating three groups based on sampling locations with 30% similarity values (green circle). Note: red, dashed circle: tendency of grouping/clustering at the stations of the IMTA site; brown, dashed circle: tendency of grouping/clustering at the stations of the monoculture site; blue, dashed circle: tendency of grouping/clustering at the stations of the reference site.

The families that are considered responsible for clustering at the farm and reference sites are *Ellobiidae*, *Columbellidae*, and *Nephtyidae*. Furthermore, there are three pairs of stations that have similar levels of macrobenthic assemblages: R1T1-R3T1, M2T2-M3T3, and R2T1-R1T2. Figure 4 demonstrates the sampling sites containing a variation of IMTA, monoculture, and reference stations, which results in minimal tendency of grouping stations based on sampling time.



**Figure 4.** The 2D ordination of NMDS based on sampling time. Note: red, dashed circle: tendency of mixed grouping/clustering at the stations of, monoculture, and reference site; brown, dashed circle: tendency of separate stations of reference site; blue circle dashed line: tendency of separate stations of monoculture and sites.

#### 4. Discussion

##### 4.1. Expressing the Macrobenthic Assemblages with Indices

Dominance, evenness, and diversity are common expressions when presenting biological communities. The indices of species diversity (Shannon-Wiener  $H'$ ), species evenness (J Pielou), and species Simpson dominance (C) are closely related to the quality of aquatic ecosystems. This relationship is based on the fact that unbalanced environmental conditions are reflected in organisms living within the water ecosystem. Ref. [16] stated that reference locations should be undisturbed by human activities, specifically by aquaculture with fish cages. As such, the relatively unpolluted water conditions and low presence of waste input from aquaculture results in a more suitable habitat for macrobenthic life, which may be the cause for the higher values in the  $H'$  diversity index at the reference site, in particular at the first sampling time. Environmental variability is believed to be the key to changes in microbenthic structure expressed by variation in index values. Depending on the location, the main environmental factors affecting the distribution and structure of macrobenthic animals reported by most authors, such as food availability, particularly organic matter, salinity and sediment characteristics, especially mud or clay content, and hydrodynamic water ecosystem, explained a significant part of macrobenthic spatial patterns [1,10,14,15,18].

The high dominance of gastropods and bivalves compared to crustaceans and ophiuroids at both the IMTA and monoculture sites was unsurprising, as they are both often dominant in macrobenthos compositions and in muddy sediments in particular [19]. Most members of gastropods and bivalves inhabit aquatic ecosystems that rely on sedimented organic materials. According to ref. [20], the Nassariidae family of mollusks generally lives on sandy and muddy substrates. They are organic and deposit feeders, feeding on decomposed organic material, such as sediment on the bottom of the water column [21]. Meanwhile, ref. [22] stated that *Anodontia* sp. are often referred to as mud shells due to them inhabiting muddy areas and spending most of their lives submersed in mud (mudflat). The bottom substrate of all three research sites consists primarily of silt sludge, which explains why *Nassarius* sp. and *Anodontia* sp. were the dominant taxa of mollusks at all three study locations. Finally, the dominance of *Tellina* sp. over other macrobenthic organisms at the IMTA and monoculture farm may be explained by ref. [23], who describes it as an organism that can adjust to being both a deposit feeder (infauna settling under muddy sediments) and a suspension feeder

on soluble organic matter in water columns. It is possible that the three taxa of mollusks as deposit feeders had benefitted from the aquaculture activities and the organic enrichment as a result.

The higher number of taxa and abundance of opportunistic polychaetes at the IMTA and monoculture sites compared to the reference site implies that the farmed sites, and the monoculture sites in particular, have been ecologically disturbed by farming activity, mostly in the form of unfed pellets and feces of farmed biotas. Concerning salmon fish farms, ref. [18] reported on the relation between abundances of opportunistic and sensitive taxa and the environmental impact of salmon cages. They found that opportunistic taxa were more abundant in the assemblages impacted by the farm and that, on the contrary, sensitive taxa were more abundant in the unimpacted reference assemblages.

Of the polychaetes taxa that were found at both the IMTA and the monoculture sites, *Sternaspis* sp. are known to inhabit fine sediment (muddy sediments) and are deposit feeders, feeding mainly on detritus. However, they may also be found in sandy mud, clay, and rocky areas and are able to live in highly saline water [24]. *Lumbrineris* sp., on the other hand, live on the bottom of fine muddy and sandy sediments. Their trophic groups can be that of predators and/or of decomposers (feeding on organic matter). *Lumbrineris* sp. is recognized as tolerant to salinity and temperature gradients [11,24]. The presence of *Capitella* sp. is related to its feeding type as a sub-surface deposit feeder. They are well known to respond to changes in sediment organic content and are therefore considered an opportunistic taxa [11,25]. Finally, *Nereis* sp. are omnivores and detritivores and feed on the surface of muddy and sandy sediments. *Nereis* sp. may also function as a suspension feeders [26,27]. It has been reported that a high abundance of some opportunistic taxa and low biomass values were observed to shift from a highly polluted phase to a transitional phase at shallow, coastal soft-bottom environments [11,28]. In this study, equitability is expressed with Pielou's evenness index. Evenness compares the distribution of individual taxa within a community [29] and looks at the numerical presence of each taxa within an environment [30]. The dominance of one or several taxa over others decreases the index value. The values corresponding to the three sampling sites showed only slight variations and are considered insignificant. However, certain stations expressed higher values than others, which means they may be influenced by dominant taxa. As shown in Table 1, the dominant taxa at all three sampling sites were *Nassarius* sp., *Anodonta* sp. (bivalves), and *Nereis* sp. (polychaete). When looking at the results of the diversity index ( $H'$ ) in Table 2, we see that the lowest values at sampling times I and II are from the IMTA station. This indicates the initial environmental disturbance when compared to the monoculture and reference stations.

#### 4.2. Abundance as an Indicator for Ecosystem Health

Physical-chemical changes in aquatic and sediment environments generally result in changes in macrobenthic abundance as a response [14,16,17]. The increased presence of polychaetes at the monoculture site implies that the environmental disturbance, especially due to the relatively large presence of organic material from farming activity, was considerably higher than at the IMTA site. It may therefore imply that the application of the IMTA system likely suppressed the impact of environmental disturbances.

Sustainable aquaculture may rely on innovation and good environmental management. Effective management strategies in the form of innovative and practical solutions can minimize the environmental impacts of aquaculture [7]. An example of this is given by ref. [9], who reported that the use of bioactivator for bioremediation was effective in promoting a shift from anaerobic to aerobic metabolism in the prokaryotic community, thus showing it to be a promising tool for mitigating the impact of fish farm sediments from aquaculture.

#### 4.3. Examining the Macrobenthic Assemblages through the NMDS Graphical Method

As shown in Figure 3, the ordinates between two stations being close together is an indication of the samples having similarities in the macrobenthic taxa composition. On the other hand, stations being further apart indicates that there are differences in the taxa composition within the group [5]. Given that

the IMTA and reference site are closer to each other than the monoculture and reference site are, this can be interpreted as the application of IMTA having suppressed the potential environmental disturbance due to aquaculture activities.

By eliminating the tendency of clustering stations based on sampling time by having a mixture of IMTA, monoculture, and reference farms at each sampling site (Figure 4), the macrobenthic assemblage was not likely influenced by seasonal variation of hydrography over the study period, but was rather influenced primarily by aquaculture activities. This may have influenced the physical-chemical environmental factors of the surrounding water and sediment composition at both sampling times. Therefore, both temporal and spatial coastal environment management needs to be applied on a regular basis.

#### 4.4. On the IMTA Farming Practice

Productivity of aquaculture may rely on design and method in order to reduce its impact on the water environment. Intensive farming using IMTA integrated with biomonitoring techniques is believed to be the right solution towards sustainable productive farming practices. It is in accordance with current needs, particularly efforts to increase the productivity of aquaculture with regard to the carrying capacity of the environment. Despite the fact of the complexity of IMTA's operation, its system is able to increase efficiency in feeding and thus reduction in organic waste [3], provide harvest diversification and economic stability benefits [31] and encourage recycling of waste nutrients from higher trophic-level biotas into production of the lower trophic-level of farmed biotas [32]. Emphasizing its potential impact on the environment, biomonitoring is an important step as anticipatory measures against the risk of interference. Thus, implementation on a wider scale through national public policy is expected to be able to change farmers' mindsets and improve farming practice. In the long term, the improvement of environmental quality will gradually be able to increase the carrying capacity of the farming area.

## 5. Conclusions

Organically rich sediments underneath farm facilities and the consequent depletion of oxygen in the sediment pore water may result in changes in *infaunal* assemblages. The application of biomonitoring using microbenthic assemblages showed sensitivity to environmental disturbance. Polychaetes exhibited differences both in number of taxa and abundance between the farm and reference site. Some of them were recognised as opportunistic taxa, i.e., *Capitella* sp., *Heteromastus* sp., and *Lumbrineris* sp. By location, the use of NMDS ordination indicates grouping of the sampling sites, clustering the IMTA, monoculture, and reference sites, whilst by sampling time, there is no tendency of grouping stations, implying that the macrobenthic structure are not influenced significantly by seasonal variation of hydrography over the study period. Environmental disturbance, especially from organic materials caused by farming activity, was considerably higher at monoculture sites compared to the IMTA sites, resulting in a higher number of polychaetes at the monoculture site, compared to the IMTA site. Based on the diversity and evenness indices and MNDS ordination, it can be concluded that the application of IMTA systems resulted in the reduction of the potential impact of environmental disturbance due to aquaculture activities. However, further assessment of the potential impact on fish farming may need to be carried out on a broader scale, both spatially and temporally. The combination of good aquaculture practice and biomonitoring application is thus needed to be applied toward productive sustainable aquaculture.

**Author Contributions:** The study was initiated by the first author S.P.P., also in charge of writing, the methodology, data analysis, and discussion sessions. The experiment was designed by S.P.P. and J.S., and both assisted in collecting the sediment samples using an Eckman grab. All co-authors (S.P.P., J.S., W., S., S.A.) contributed to discussion on the content and detailed reviews of the manuscript. W. made a review of the draft manuscript focusing mainly on data analysis and the performance of the graphs, while J.S., S. and S.A. focused on the data analysis and discussion and interpreting the data. The identification and enumeration of the microbenthic specimens were carried out by J.S. and S.P.P. All co-authors made thorough reviews in the final stage of the writing

to discuss the interpretation of the findings and relation with literature. All authors have read and agreed to the published version of the manuscript.

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