Linking Chemical and Physical Parameters of a Coastal Water Ecosystem with Macrobenthic Assemblages to Asses environmental Disturbance

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RESEARCH ARTICLE

Linking chemical and physical parameters of a coastal water ecosystem with macrobenthic assemblages to assess environmental disturbance

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Abstract

Environmental disturbance, whether natural or anthropogenic, may change the structure of macrobenthic assemblages (across various spatial and temporal scales) in terms of taxa richness, animal abundance, and animal biomass. Such changes may be used as an indicator and can provide a quantitative basis when assessing the levels of disturbance. This study is aimed to assess environmental disturbance caused by fish farming by linking chemical and physical parameters to differences in the structure of macrobenthic communities. The study sites comprised coastal water ecosystems in the Awerange Gulf, South Sulawesi, Indonesia. The study compared macrobenthic communities associated with polyculture and monoculture farming against reference sites. The tendency of reduction in their abundance occurred at polyculture and monoculture sites, compared to the reference site, i.e. 5882 ind.m^{-2}, 3531 ind.m^{-2}, 2112.5 ind.m^{-2}, respectively. The results from multivariate and graphical methods using NMDS plots, k-dominance curve, and ABC curves, tend to be in accordance with the results from index values, thus both methods may be used as a apart of rapid assessment of level of environmental disturbance in coastal water ecosystem. Carbon and nitrogen contents in sediment and dissolved oxygen (DO) were the most chemical and physical parameters influencing structure of macrobenthos (r=0.457; BIO-ENV).

Keywords: Macrobenthic assemblages, Awerange Gulf, chemical and physical parameters, fish farm, and multivariate analysis

INTRODUCTION

Macrobenthic animals are organisms that spend a part or all of their lifespans in the bottom of water sediment (sessile, crawling, digging holes, or building tubes), have an important role in decomposition and mineralization processes of organic material in the water, as well as occupying several trophic levels in the food chains [1]. Their structure varies spatially and temporally, and are sensitive to environmental disturbance, especially caused by organic enrichment [2], thus considered as an important part of biomonitoring procedures as a formal protocol in assessing the status of water [3,4]. An environmental disturbance, whether natural [4] or anthropogenic [5], may change the pattern of macrobenthic assemblages spatially and temporally in taxa richness, abundance, and biomass. The changes may be used as an indicator of community disturbance and provide an assessment of the levels of disturbance [6]. The responses to an environmental disturbance can be varied, depending on source and level of disturbance, i.e. a shift in the proportions of different phyla, changes in relative distribution of species abundance and biomass with increasing levels of disturbance, reduction in trophic complexity, and increase in densities of opportunistic taxa are some of [7, 8].

The changes in the dominance pattern of macrobenthic assemblages based on both abundance and biomass can be assessed using the Abundance/Biomass Comparison (ABC) method [9]. The ABC method is used to determine a shift in the proportions of different phyla and in relative distributions of abundance and biomass among taxa. Depending on the level of disturbance, the biomass curve may lie above the abundance curve (for undisturbed areas) or under the abundance curve (for heavily/grossly disturbed areas) or they may be closely coincident for its entire length or may cross each other one or more times (for moderately disturbed areas) [10].

The dominance (and intrinsically diversity) of the assemblages may graphically be illustrated by cumulative k-dominance curves. This graphical method is generated by plotting cumulative ranked abundances against log species/taxa rank [11]. The graphical method using k-dominance curves for both abundance and biomass usually plot on the same graph [12, 8].

RESEARCH METHODS

The sampling sites were located at surrounding the fish farming cage in the Awerange Gulf, South Sulawesi, Indonesia at the coordinates between 79°0500' – 79°1500'S and 953°1500' – 953°2000'E. Sampling period was conducted between October 2014 to April 2015. The samples were taken using Eckman grab, from three main areas, i.e. polyculture, monoculture, and reference areas, consisting 3 stations with 3 replicates.

A variety of different methods were used to assess the patterns using the PRIMER 6.1.5 software packages, i.e. indices, multivariate and graphical methods. Number of taxa (S) and Margalef's index were used to compare taxon richness between sites and times. The diversity of the macrobenthic assemblages was analysed using Shanon-Wiener index (H') after log (x+1) transformation. Pielou's evenness index was used to express equitability index [10]. Diversity of macrobenthic assemblages was expressed by the diversity index of Shannon-Wiener (H'), using the following formula [13]:

$$H' = \sum_{i=1}^{s} -(P_i * \ln P_i) \qquad (1)$$

where, H' = the Shannon diversity index; P_i = fraction of the entire; population madeup of species i; S = numbers of species encountered; ∑ = sum from species 1 to species S. Pielou's Evenness index expresses composition of a number of individuals in any genus that is within the community. It is gained by comparing index diversity with their maximum value and calculated by formula [15]:

$$E = \frac{H'}{H'\ \text{maximum}} \qquad (2)$$

Where, E= population index; H'= the diversity index; H' max= maximum the diversity index / ln S.

The dominance of the assemblages was graphically illustrated by cumulative *k*-dominance curves for each sampling time. The graphs of each station were plotted on the same figure. Non-metric Multi Dimensional Scaling (NMDS) of Bray-Curtis similarities was used to provide a visual representation of differences between sites over time. The initial analysis incorporates all sites at all times to observe if there was any tendency of separation between stations. The dominating taxa were then superimposed on the MDS plots as bubble plots to assess their roles in configuring the ordinations. The graphs generated from comparison between macrobenthic biomass and abundance which produces drought ABC curves was processed using the PRIMER software version 6.1.

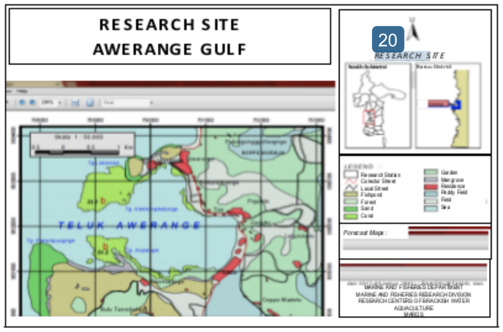

Fig. 1 Map of Awerange Gulf, Barru, South Sulawesi as a study site.

RESULTS AND DISCUSSION

Diversity and Evenness Indices

The abundance of macrobenthos were found highest at the reference site (K), i.e. 5880 ind.m^{-2} in the dry season and 5413 ind.m^{-2} in the rainy season, compared to the two other sites. Macrozoobenthic abundance encounted 3067 ind.m^{-2} in dry season and 4000 ind.m^{-2} in rainy season at monoculture site; whilst those at polyculture encounted 1680 ind.m^{-2} in the dry season and 2547 ind.m^{-2} in the rainy season.

The values of diversity index (H ') ranged between 1.66 – 1.95 at all sampling sites. This may indication of relatively low to moderate diversed community [13, 14], as shown in Fig. 2a. The values showed fluctuated by time and location. This may relate to response of macrobenthic assemblages to the enrichment of organic material sedimented, especially discharge of fish pellet and metabolic waste of farmed fish, as it has been reported by Ref [3]. Diversity index at reference site (K) is lower than those at the polyculture and monoculture sites. This may because organic materials generated from fish farming activities has been dispersed away to certain area forced by water currents, pressing certain genus that are not able to adapt to organic materials, thus reducing the their abundance. In conditions of high pressure environment, certain species will take advantage of these conditions to improve reproduction, so that the population increases compared with other organisms are not able to survive [3, 13].

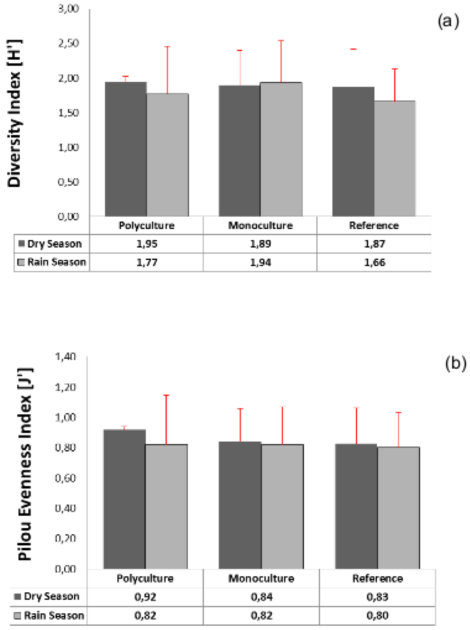

Fig. 2 Comparisan of diversity (a) and evennes (b) indices among sampling sites (+SD).

Fig. 2b shows values of Pielou's evennes index, comparing dry and rain season, ranged between 0.80 – 0.92. This indicates that the macroventhic assemblages realtively evenly distibuted among the sites and no indication of dominant taxa inhabiting the studied sites. The lowest value of the index occured at the reference site, compared to two other sites. This may be because of the ecological pressure from activities in the surrounding waters, not only form spread out of organic material generated from fish farming, but also can be from urban runoff waste and industrial waste that is carried away by the waves.

The k-dominance curves

Based on the *k*-dominance curves, Station KJ1M1T2 (monoculture site; second sampling time) configures on the bottom of the curves, indicationg that the station has the most diverse area compared to other stations, as in Fig. (3).

Meanwhile, Station K2T1 (Reference site; second sampling time) and Station K1T1 (Reference site; first sampling time) has less diverse areas. This is in accordance with the values of Pielou's evennes index and Shanon-Wiener diversity index, as has been shown in Fig. 2.

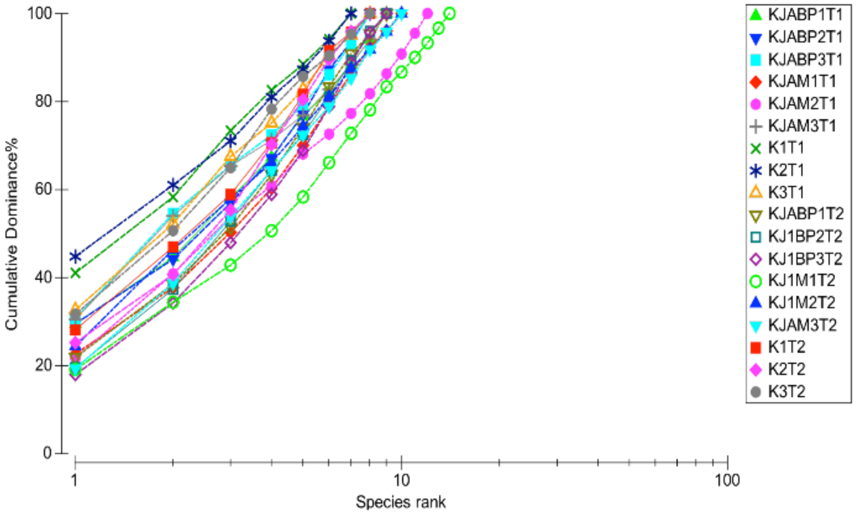

Fig. 3 The k-dominance curves for each sampling site.

Ordination- Non Metric Multidimensial Scaling (NMDS)

The NMDS ordination plots showed separation among the group of stations, i.e. polyculture site, monoculture site, and reference site, suggesting that their composition in macrobenthic assemblages are different in species number and abundance (see Fig. 4).

Based on the macrobenthic structure, certain taxa were superimposed on the MDS plots as bubble plots to assess their roles in configuring the ordinations. There were two dominant taxa, i.e. *Vexillum* sp. and *Collumbonella* sp., which are responsible in configuring certain stations on the ordination. The presence of *Vexillum* sp. in the stations tends to drive position of stations to the right of the ordination. Similarly, the presence of *Collumbonella* sp. in the stations also tends to drive position of stations to the right of the ordination. In general, the higher the number of *Vexillum* sp. and *Collumbonella* sp., the more direction to the right on the ordination. The dashed lines on the ordination showed tendency of clustering the stations based on their location/site, i.e. polyculture, monoculture, and reference sites. This may indicate that the three sampling locations have different structure of macrobenthos, although each station performed varied in its macrobenthic composition.

Abundance-Biomass Comparison (ABC) curves

Abundance is one of the parameters of the dynamics of macrobenthos inhabiting sediments of coastal water ecosystem. Moreover, abundance of macrobenthis may perform varied from one region to another. High and low abundance of an organism depends also on the surrounding physico-chemical environmental factors. The results of the analysis of macrobenthos abundance in all areas of research in detail are presented in Fig. 5 and Table 1.

In general, macrobenthos were found abundantly in all sampling sites, except at polyculture site, which were found only 1680 ind.m^{-2} in October 2014. The macrobenthos exhibited highly abundant at polyculture site, monoculture site and reference area (K) indicates that the sites are relatively favorable for the animals. This is consistent with the statement [16] which divides the abundance individual criteria (in genus) into four groups: 0-200 ind.m^{-2} as not abundant; 200-500 ind.m^{-2} moderately abundant; 500-1000 ind.m^{-2} as abundant; and more than 1000 ind.m^{-2} highly abundant. Compared to the 21 families found in all sampling sites, Turritellidae has the highest composition ranged between 853 - 5067 ind.m^{-2}. Yet, there was difference in their abundance between monoculture and polyculture sites, which ranged between 853 - 1827 ind.m^{-2} compared to the reference area (K), which ranged from 5067 ind.m^{-2} in rain season and 3720 ind.m^{-2} in dry season. This may relate to some members of the family have a low tolerance to environmental disturbance. This is consistent with the statement of [17] that Turritella sp. is an indicator species for water pollution.

Family Capitellidae, Nereidae, and Spionidae found only in polyculture and monoculture sites, while they were not found in the reference area (K).

Capitellidae consistently appeared at both polyculture and monoculture sites in each sampling station. They are considered as opportunistic taxa. The sediment properties of the sites have been influenced by fish farming activities, especially by the enrichment of organic material from the unfeed pellets and also the biological activity of farmed fish. This is in accordance with the statement [3] that among other benthic animals, Polychaeta is considered to be more sensitive to organic enrichment and respond to rapid changes in the diversity and abundance. Capitellids inhabit the sediments as a digger worm or sub-surface deposit feeders which prefer inhabit muddy than sandy mud substrate. Muddy sediment provides organic particulates as food source for capitellids [18].

In the reference area (K), the highest dominance value compared with the cultivated area is 0.70 in the rainy season and 0.50 in the dry season. Dominance index value of the reference area (K) which is close to 1 is quite high. It can be caused by certain species are more tolerant than other species on the environmental conditions. This condition indicates the occurrence of ecological pressure resulting kind in the reference area (K) is reduced. A high dominance index value expressed high concentrations of domination (there are individuals who dominate), otherwise a low index score of domination expressed low concentrations (no dominant) [14]. The results of calculation of the index H 'macrobenthos in the area of research, as a whole show that the value of diversity index (H') ranged from 0.65 to 2.01 (Table 2). The index value of diversity in the sampling of the rainy season in Polyculture site was 1.47 while in the dry season sampling was 2.01.

The index value of diversity in the sampling during rainy season in monoculture site was 1.57 and 1.65 in the dry season one. Value diversity index (H ') in the area of reference (K) for sampling the rainy season is 0.65, while in the dry season reaching 1.19.

According to [14], value of biodiversity is considered low when H '<1, is considered moderate when 1 <H' <3, and is considered high when H '> 3. In general, based on these criteria, diversity index value obtained in this study both inter-regional and sampling time were still show prevalence and stability of macrobenthos. The condition of the study area based on the diversity index obtained by [19] shows water sampling sites in the criteria being polluted (H '<2).

Biomass and abundance curves at Monoculture and Polyculture sites of wet and dry season sampling, abundance curve contiguous with the curve of biomass and already tangent at the end of the curve.

This indicates that the Gulf waters, especially in polyculture or monoculture farming area began to experiencing moderate pollution. This allegedly caused the enrichment of organic material derived from fish feed so as to affect the lives of macrobenthos because it can cover the base substrate surface waters [14]. This is in accordance with the observations of diversity (H '<2) are included in the criteria for being polluted by [19].

In the reference area (K) in the dry season when sampling shows biomass curve is above the abundance curve. Based on [20], the shape of the curve in Fig. 3 shown that the reference site is in the category as not disturbed area. This is shown in the biomass curve that lies above the curve abundance. Conditions of the site allowed macrobenthos to proliferate and survive normally so there is no change in the structure of macrobenthos. Under conditions of a stable environment and a low level of disturbance, macrobenthos community will be dominated by conservative species. Conservative species is a species that has a "K-selection" life strategy which is characterized by a large body size, a relatively long life span, thus dominant in biomass. In conditions that are not disturbed, macrobenthos community is able to maintain species richness, biomass and abundance at the minimal level of stress [21].

The use of ABC curves is able to detect the condition of studied sites. The ABC curves categorized the reference area (K) as undisturbed by pollution. The condition is also supported by the results of physico-chemical measurements of the waters where the DO and pH is a major factor limiting growth and development and macrobenthos still meet the quality standard values for marine life [22]. Reference [23] stated ABC analyses on the data of macrobenthic structure in reclamation habitats of estuarine islands in Yangze Estuary, China was able to show a deteriorated change and its intensity occurred in the reclamation habitats, however; self-restoration of macrobenthic diversity be possible, thus considered effective as a tool to assess environmental disturbance. Furthermore, recovery process will depend on the intensity of disturbance. Reference [24] reported that 2 years substantial recovery of macrobenthic community occurred, and may be complete after 5 years; yet, slight difference from the reference habitats may happened along with on-going instability of the assemblages.

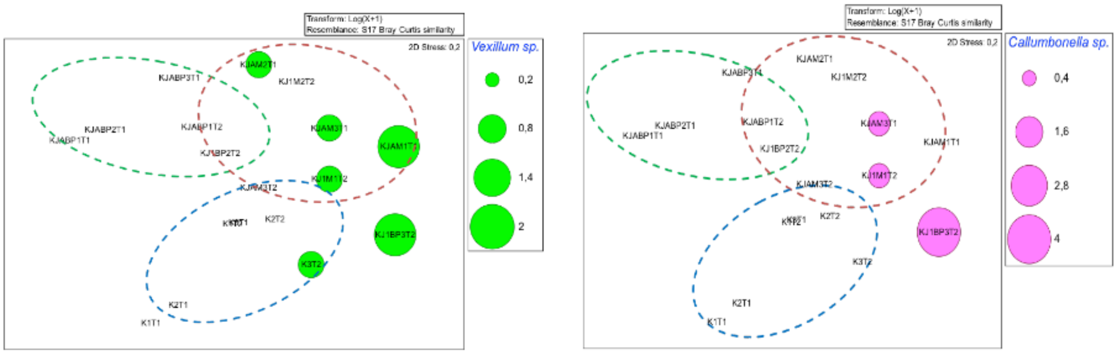

Fig. 4 Superimposed *Vexillum* sp. and *Collumbonella* sp.on the MDS plots as bubble plots to assess their roles in conuring the ordinations.

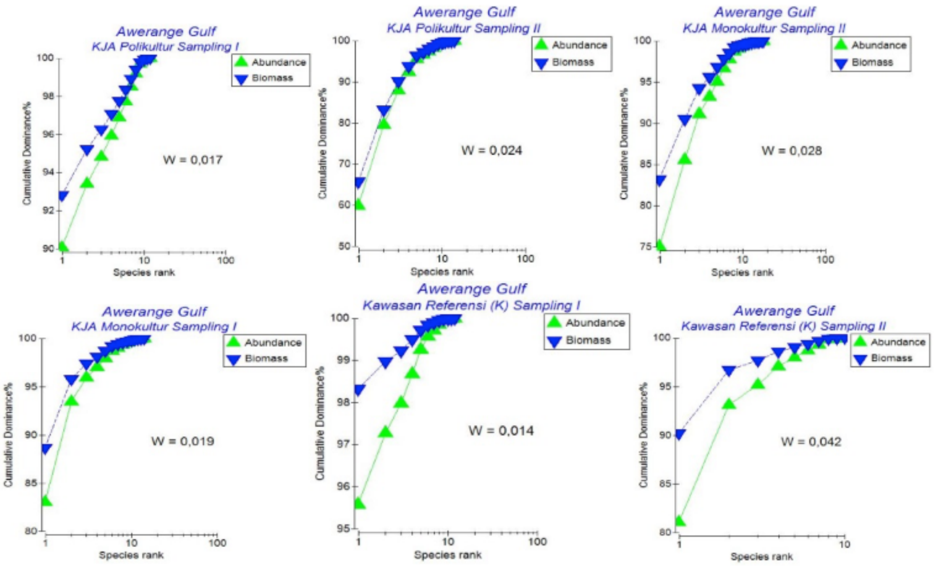

Fig. 5 A curve comparison of abundance biomass of macrozoobenthos.

Linking chemical and physical parameters to macrobenthic assemblages

The table 1 shows the correlations between physical-chemical factors, substrate granular composition and the carbon and nitrogen content with the abundance of mollusks were analyzed using BIO-ENV on PRIMER V.6.1.5 software.

Table 1 Analysis of the correlation between biotic and abiotic components

No.	Correlation (r)	Variable [a]	Variable amount
1	0.457	4,7,8	3
2	0.447	1,7,8	3
3	0.437	1,4,7,8	4
4	0.416	2,4,7,8	4
5	0.41	1,3,4,7,8	5
6	0.401	1,2,4,7,8	5
7	0.394	1,2,7,8	4
8	0.391	3,4,7,8	4
9	0.388	2-4,7,8	5
10	0.388	1-4,7,8	6

[a] Variables: 1=pH, 2=Temperature, 3=Salinity, 4=DO, 5=Sand, 6=Silt, 7=C Content, and 8=N content.

Based on the table above, the correlation between the macrobenthic abundance with DO, C content and N content have the greatest degree of correlation, which is 0.457. This indicates that the value of DO, the carbon and nitrogen content are the abiotic components that has the most influence in the abundance of mollusks in the Awerange Gulf.

CONCLUSION

Macrobenthic abundance was spatially and temporally different between the control and fallowed sites, which reflected spatial and temporal variability in taxa richness, evenness, and diversity. Variability between sites within each sampling time resulted in complex patterns in the infaunal structure. Capitellidae consistently appeared at both polyculture and monoculture sites in each sampling station. They are considered as opportunistic taxa. The results from multivariate and graphical methods using NMDS plots, k-dominance curve, and ABC curves, tend to be in accordance with the results from index values, thus both methods may be used for rapid assessment of level of environmental disturbance. In particular, Vexillum sp. and Collumbonella sp. are responsible more in configuring certain stations on the NMDS ordination. Carbon and nitrogen contents in sediment and dissolved oxygen (DO) were the most chemical and physical parameters influencing structure of macrobenthos (r=0.457; BIO-ENV).

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