Journal of Tropical Biodiversity and Biotechnology
Volume 06, Issue 02 (2021): jtbb61507
DOI: 10.22146/jtbb.61507

Research Article

Macroinvertebrates Reveal Water Quality Differences in Various Agricultural Management

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Submitted: 21 November 2020; **Accepted:** 23 March 2021; **Published online:** 20 May 2021

ABSTRACT
Monitoring benthic communities under different agricultural practices and management could potentially become an important tool to evaluate ecosystem health and stability. Benthic macroinvertebrates have been widely used as water quality bioindicators. This study aims to analyze macroinvertebrates in rice field ecosystems affected by three types of management practices, including conventional, semi-organic, and organic. This study was conducted in Sumberjambe and Kemiri, Jember Regency. Macroinvertebrate samples were collected at three sampling stations for each type of rice field, giving out a total of nine stations. Through Ekman grab, samples were obtained and transferred into a jam jar filled with 70% ethanol using a brush. Six ecological indices were selected to describe the diversity of each station. The Principal Component Analysis (PCA) using PAST3 software provided the sample's preference towards the stations and the higher taxa (Class). We also analyzed the similarity of the macroinvertebrate communities between the sampling stations using the Jaccard Similarity Index (JSI). A total of 11 families and 4 classes of macroinvertebrates are recorded. The Shannon-Wiener index shows high diversity for stations with organic management practices (1.318), while the Evenness index shows the highest value for conventional stations (0.9449). The Jaccard similarity index value reports two stations with semi-organic stations as well as semi-organic and organic stations having the highest similarity (JSI = 76.47%), while the lowest similarity value is characterized for conventional and organic stations (JSI = 13.19%).

Keywords: agroecosystem, diversity, macroinvertebrates, water quality

INTRODUCTION
Macroinvertebrates have been commonly used as biological indicators to assess water quality. Previous studies have revealed that macroinvertebrates could detect various contaminants, such as heavy metals (Qu et al. 2010), crude oil (Vinson et al. 2008), and pesticides (Berenzen et al. 2005). Macroinvertebrates are considered better to monitor water quality than standard instruments since they have a broader detection range and a longer exposure time to pollution (Duran 2006; EPA 2012). Moreover, a study by Choe et al. (2013) revealed that the macroinvertebrate diversities show informative and accurate results to determine the ecological function of irrigation ponds in rice cultivation ecosystems.

In the agroecosystem, the application of pesticides and fertilizers affects water quality. Since the rice plants easily adsorb the water contaminant and store it in its grain, the application of pesticides and inorganic fertilizers might also determine the quality of rice products (Pingali & Roger 2012). However, the use of inorganic fertilizers and pesticides produces residues that contaminate the water and change the natural physical -chemical condition of the water. The changing physical-chemical conditions of water, hereby, change the surrounding communities of benthic macroinvertebrates (Rizo-Patrón V. et al. 2013). Monitoring the benthic macroinvertebrates as bioindicator communities, thus, plays a crucial role in indicating the water quality as the response of the additive additions.

Monitoring benthic communities under different agricultural practices and management could potentially become an important tool to evaluate ecosystem health and stability. Despite there has been an introduction of organic and semi-organic rice cultivation, only a few studies have conducted research on the macroinvertebrates in various agroecosystems in Indonesia (i.e. Furaidah & Retnaningdyah 2013). Therefore, this study was carried out using lentic waters in rice fields under three different management practices (i.e. conventional, semi-organic, and organic) to assess the impacts of chemicals from fertilizers and pesticides on the ecosystem. The conventional systems use both inorganic fertilizers and pesticides, while organic systems use only organic additions. The semi-organic systems most likely combine inorganic pesticides and organic fertilizers. This study aims to analyze the findings of macroinvertebrates in 3 types of rice field management.

MATERIALS AND METHODS

Study Sites

This study was conducted in Sumberjambe and Kemiri, Jember, Indonesia, on September 20-21, 2020 (Figure 1). The data collection was done in the dry season, with the average amount of rainfall about 34 mm^3 (BPS Jember 2021). Macroinvertebrate samples were collected at three sampling stations for each type of rice field (i.e. conventional, semi-organic, or organic), giving out a total of nine stations (Table 1). These three types of management were selected to provide comparable information on the different impacts of the management practices on the benthic macroinvertebrate communities inside the ecosystems.

All three types of rice fields in this study were observed to be in the vegetative phase when data was collected. The water was supplied from the surroundings river through irrigation channels. Conventional rice fields used both inorganic pesticides, fungicides, and inorganic fertilizers. It used 'Phonska' branded-fertilizers with the composition consists of Nitrogen (N) 15%, Phosphate (P) 15%, Kalium (K) 15%, Sulphur (S) 10%, max water 2%. In order to control the pests, 'Fenite' branded-pesticides was applied with the active ingredients of emamektin 75g/l and 'Zole' branded-fungicides with the active ingredients of difenocolazole 250 g/l. Semi-organic rice fields also used 'Zole' inorganic fungicides but combined with organic fertilizers made of cow manure. For full-organic rice fields, organic fertilizers were the fermentation of 70% cow manure, 10% banana stems, 10% bran (i.e *dedak*), corn roots, water, and bacterial starter 10%. The organic pesticides/ fungicides were made of cow urine, garlic, Kipahit (*Tithonia diversifolia*), and Mimba (*Azadirachta indica*).

Data collection

For each station, sampling was repeated at three points to ensure objectivity. Sampling was done using Ekman grab with dimensions of 15x15x18 cm. We used Ekman grab to collect macroinvertebrate samples living submerged in the water and those living on the surface of sediments and water surface. Through Ekman grab, water and sediment samples were obtained and then poured into the layered strainer with different sizes ranging from 2.36 mm, 1.5 mm to 0.5 mm, in order to sift the sediments from the samples. A brightly colored plastic plate and a brush were also used to pick out macroinvertebrates from the litter or the sediments. The benthic macroinvertebrates were then transferred into a jam jar filled with 70% ethanol using a brush. The macroinvertebrates were sorted based on their Order. Then, identification was made using a light microscope by putting the samples in a disposable petri dish. The samples were classified and counted to the families of the taxon using Gooderham and Tsyrlin (2002) and Lehmkuhl (1979).

Table 1. The sampling stations and the comparison of treatments for each management practice type.

Stations	Types	Fertilizer	Pesticide/fungicide
S1-S3	Conventional	Phonska (1 kg/600 m^2) every 2 weeks, week 5 to 9	Fenite (active ingredients: Emamektin), Zole (active ingredients: difenocolazole)
S4-S6	Semi-organic	Organic (10 kg/800 m^2) every 2 weeks, week 3 to 9	Zole (active ingredients: difenocolazole)
S7-S9	Full Organic	Organic (20 kg/900 m2) every 2 weeks, week 3 to 9	Organic

Data analysis

We estimated family richness and its abundance for each management practice type. The graphs of family numbers and individual numbers with stations as x-axis were shown to illustrate the trend on management types. Six ecological indices were selected to describe the diversity of each station (i.e. individual and taxa number, Shannon-wiener, Margalef, Dominance Simpson, and Evenness index). Moreover, the Principal Component Analysis (PCA) using PAST3 software provided the sample's preference towards the stations and the higher taxa (Class).

We also analyzed the similarity of the macroinvertebrate communities between the sampling stations using the Jaccard Similarity Index (JSI). The JSI was used to determine the degree of similarity and dissimilarity ranging from 0-100% based on the number of species in each community (Hao et al. 2019; Oluyinka Christopher 2020).

Below was the formula used in this study:

a. Shannon-wiener (Odum & Barrett 1971)

$H = - \Sigma n_i . N^{-1} . \ln(ni.N^{-1})$

where H = Shannon-wiener index
n_i = individual number of particular species i
N = total individual number of all species found

b. Margalef (Clifford & Stephenson 1975)

$$\mathrm{Dmg} = \frac{S-1}{\ln N}$$

where Dmg = Margalef index
S = total number of species
N = total number of individuals in the sample

c. Dominance Simpson (Brower et al. 1990)

$$Id = \frac{\Sigma n_i(n_i - 1)}{N(N-1)}$$

where Id = Dominance Simpson index
n_i = individual number of particular species i
N = total individual number of all species

d. Evenness (Krebs 1972)

$$E = \frac{H}{Hmax}$$

where E = Evenness index
H = Shannon-wiener index
Hmax = Log_2S
S = total number of species in the sample

e. Jaccard (Jaccard 1900)

$$J = \frac{B + C}{A + B + C}$$

where J = Jaccard Index
A = number of species shared by two communities
B, C = number of species unique to each of the two communities

RESULTS AND DISCUSSION

A total of 11 families in 4 classes were recorded and grouped as Gastropoda, Polychaeta, Clitelatta, and Insecta. The number of individuals was shown varied between S1-S9 (Figure 2). Among other stations, S9 had the highest number of Gastropods. This result was supported by the finding of *Pomacea canaliculata*, which could easily adapt to an organic ecosystem (de Brito & Joshi 2016). For Insecta, the number of individuals increased for S5 -S9, while the number of Clitellata decreased for S1-S9. Moreover, Polychaeta was present only at S4-S6.

Based on the average number of families, the results showed that the Gastropoda distributed more equitably to all stations compared to other groups. Despite these results, a noticeable result can be seen at S9 with the highest individual number of Gastropods. Both Clitellata and Polychaeta showed decreased family richness for S1-S9. On the contrary, the family richness of Insecta increased for S1-S9, with S8-S9 had the highest families. The individual number trend of Clitelatta, Polychaeta, and Insecta was apparently in agreement with the results of the family number. The individual number of Clitellata and Polychaeta were decreasing, while Insecta was increasing for S1-S9, respectively.

Most of the Insecta found in this study, including Philorheithridae, Hydrophilidae, and Chironomidae are indicators for clean waters (Gooderham & Tsyrlin 2002). Thus, it was completely understandable if these families were higher in the organic rice fields with minimum contaminants. On the other hand, the findings of Clitelatta and Polychaeta, such as Tubifex sp. and Nereidae showed that the water had been contaminated by organic pollutants as in conventional and semi-organic rice fields (Martins et al. 2008; Swari et al. 2014).

The macroinvertebrates were scientifically proven to be very important for maintaining ecosystems' balance in the waters and surrounding areas (Magbanua et al. 2010). Based on the results, organic rice fields have a higher number of aquatic macroinvertebrate families. In contrast, the conventional rice fields (i.e. S1-S3) had a more simple composition of macroinvertebrates, with Naididae of Clitellata predominating the stations, indicating polluted water with organic contaminants (Martins et al. 2008).

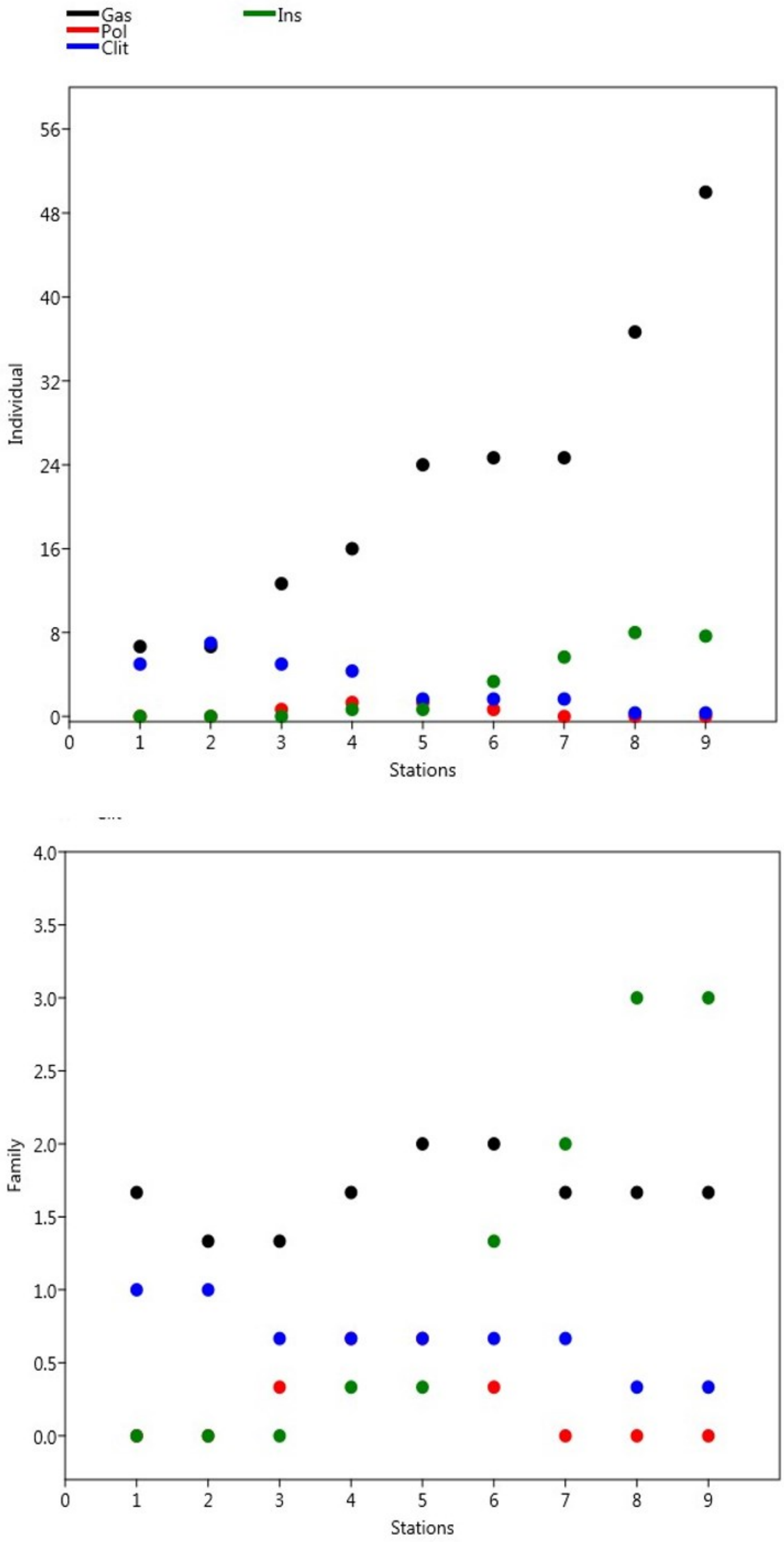

Figure 2. The average number of individuals and families at sampling stations. Keys: Class of macroinvertebrates described by color. Gastropoda (Gas): Black, Polychaeta (Pol): Red, Ciellata (Clit): Blue, and Insecta (Ins): Green.

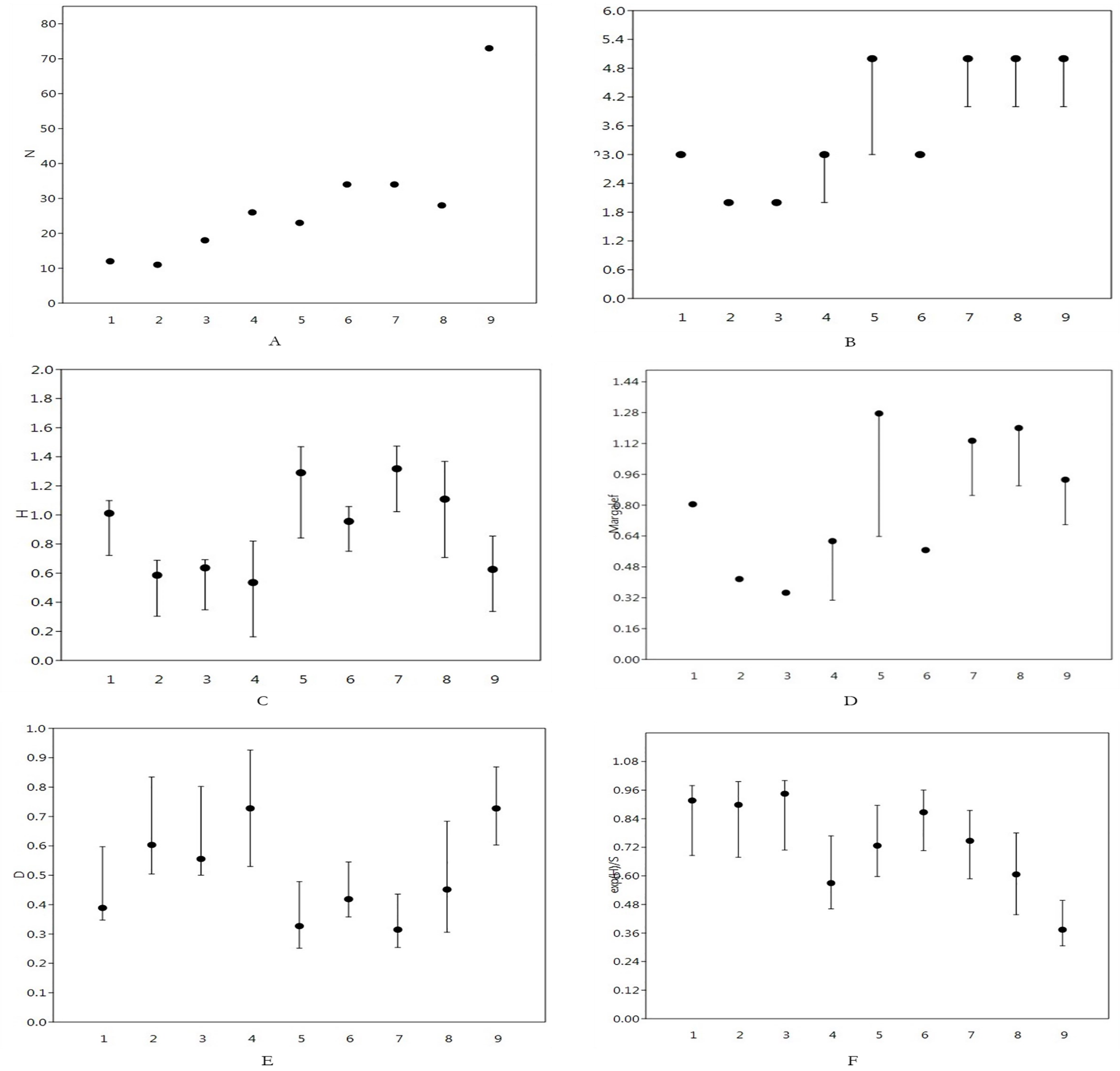

Figure 3. Statistical index based on PAST3 analysis (Alpha Diversity Indices) A) Total number of individuals (N); B) Total number of families (S); C) Shannon-wiener index (H'); D) Margalef Species Richness Index; E) Dominance Index (D); F) Species Evenness Index. All graphs used stations as the x-axis.

Ecological indices

The number of individuals showed a steady increase for S1-S8, while the highest number was recorded for S9 (Figure 3A). At semi-organic rice fields (S4- S6), there was a high number of Ampullaridae and Pachychilidae. Moreover, Polychaeta (Family Naereidae) was also found. It was clear that S7-S9 had the highest taxa for the taxa richness compared to other stations (Figure 3B).

The Shannon-wiener index showed a high diversity of macroinvertebrate) at S5, S7, and S8, with S2 and S4 had the lowest (Figure 3C). The Margalef species richness index described similar conditions (Figure 3D), with the difference that station 6 had lower diversity than the results of the Shannon-wiener index.

The Simpson dominance index illustrated the opposite condition (Figure 3E), with S2-S4 showed the highest dominance. It was reasonable since low diversity could also mean high dominance. Furthermore, the Evenness index also showed a value close to 1 at S1-S3, reflecting low diversity and populations (Figure 3F).

The number of families in organic rice fields was higher compared to other agroecosystems. Moreover, based on the Shannon-wiener index, S7 with organic management type showed the highest diversity index (H=1.318). Then, the second highest with a small difference with the first one was S5 with semi-organic management practices (H=1.291). We assumed the use of organic fertilizers used in semi-organic stations might accommodate the various types of macroinvertebrates to live. In addition, the high presence of Insecta in organic stations indicates the stability of the ecosystem even without the addition of chemicals from pesticides or inorganic fertilizers (Gooderham & Tsyrlin 2002). There were 6 insect families found in the organic stations (Caenidae, Philorheithridae, Tipulidae, Gerridae, Hydrophilidae, Chironomidae), but only Tipulidae was found in the semi-organic station (i.e. S5).

Philorheithridae is the indicator of clean water (Morse et al. 2019). They not only capture and utilize a wide variety of nutrients in many forms but also transforming them for use by other organisms in freshwaters and surrounding riparian areas (Morse et al. 2019). Caenidae is commonly used as the indicator of possible low-organic polluted water (Hilsenhoff 1988). Tipulidae and Gerridae are known as an indicator of water conditions with moderate water quality (Pritchard 2003; Priawandiputra et al. 2018), while Hydrophilidae, and Chironomidae are indicators for clean waters (Gooderham & Tsyrlin 2002).

Principal Component Analysis (PCA)

The PCA result defined three components. First, the family was a specific taxa group. Second, a Class described a more general classification of ecological roles. The third was the taxa preference for 9 stations based on the biplot analysis (Figure 4). Ampullaridae was considered as an outlier due to a large number of findings. Thus, Ampullaridae, together with Pachyllidae, hereby, were the reasons for the high numbers of Gastropods. Ampullaridae was family taxa found in all types of rice fields. This family most likely has high adaptability and high tolerance in any kind of environment, making this family highly found in both conventional and organic stations. We identified one of the Ampullaridae species found in the sites as *Pomacea canaliculata*. This species is known to have high resistance to various environmental conditions and even high adaptability to other areas as an invasive species (de Brito & Joshi 2016). This snail has been introduced in Indonesia around 1983, and currently, it can be easily found in various wetlands in Indonesia (Marwoto & Nur 2011). Since this species has an ecological role as a herbivore and a pest because of its rapid reproduction, it is reported to soon become one of the most devastating rice pests in Asia (Naylor 1996). These snails are distributed for various reasons, such as the aquarium trade, foodstuffs, fish pond cleaners, and ship introduction (de Brito & Joshi 2016).

Insects had a location preference towards the S7, S8, S9. Chironomidae and Hydrophilidae were clustered in the middle, and Philorheithidae and Gerridae approached the center. The composition of most insects found in this study indicated good water quality, therefore, affects their preference towards organic stations with no addition of inorganic pollutants from the fertilizers and pesticides.

Clitellata and Polychaeta were plotted closer to the center and have a preference for S1 and S2. The members of Clitellata and Polychaeta found in this study however revealed poor water quality. Therefore, the preference of *Tubifex* sp., as the member of Class Clitelatta and Family Nereida, on

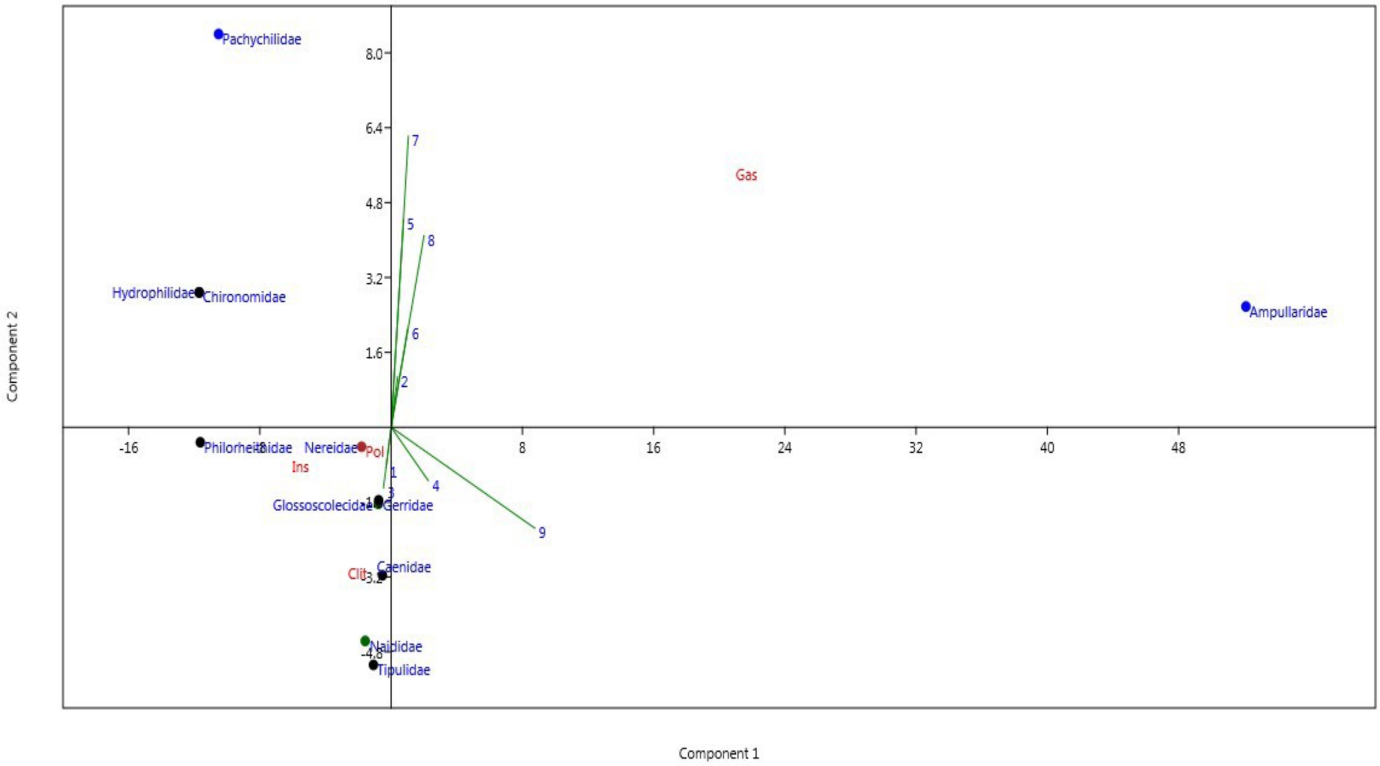

Figure 4. Biplot analysis on Principal Component Analysis (PCA) of collected macroinvertebrate families versus 9 sampling stations. Classes as groups are also provided. Keys: Gastropoda (Gas), Polychaeta (Pol), Cliellata (Clit), and Insecta (Ins).

conventional stations indicated highly polluted water by organic contaminants (Martins et al. 2008; Swari et al. 2014).

Jaccard Similarity Index (JSI)

We analyzed the similarity of the species between stations using the Jaccard similarity index (Table 2). The highest similarity was found for S5 and S6, as well as S6 and S7 (JSI = 76.47%). This value reflected the number of species of macroinvertebrates at the two stations had no significant difference.

S3 and S9 had the lowest similarity based on the JSI value (JSI = 13.19%), representing large differences in the number of species for conventional and organic rice fields. A similar value can also be seen for S1 and S9 (JSI = 14.12%) as well as S2 and S9 (JSI = 19.05%), reflecting different compositions in macroinvertebrates in conventional and organic rice fields, respectively.

Locally, in Jember, organic farming development often leaves treatment to maintain water quality since water is an important component to maintain the cycle and physiological processes of plants, especially rice. Another study shows that rice is categorized as a bioremediation plant that stores most of the chemical content (Ali et al. 2018). The chemical substances that are absorbed and stored in several parts of the plant will reduce the quality of the products and further affect the consumer's health. Monitoring water quality, thus also, is needed as a measurement model for assessing chemical-free products (Sivaranjani & Rakshit 2019).

Based on this study, we recommend continuous monitoring of macroinvertebrate communities to detect and avoid pollution early. Furthermore, we suggest that it is important to apply bioremediatory crops for organic farming as a barrier to avoid high exposure to chemical pollutions caused by surrounded conventional farming.

Tabel 2. Values of Jaccard Similarity Index (JSI) in 9 Stations (%).

Stations (S)	1	2	3	4	5	6	7	8	9
1		43,48	53,33	21,05	40,00	26,09	26,09	15,00	14,12
2	43,48		62,07	43,24	52,94	35,56	35,56	46,15	19,05
3	53,33			27,27	34,15	23,08	23,08	30,43	13,19
4	21,05				57,14	66,67	53,33	66,67	48,48
5	40,00					76,47	70,18	50,98	29,17
6	26,09						76,47	58,06	41,12
7	26,09							61,29	39,25
8	15,00								41,58
9	14,12								

CONCLUSION

The organic management practice for rice cultivation increases the diversity of aquatic macroinvertebrates compared to conventional and semi-organic management. The result of PCA analysis also showed that Gastropoda and Insecta have a high preference for organic rice fields with minimum organic pollutions. Furthermore, JSI analysis revealed the diversity and numbers of macroinvertebrates were significantly different in conventional and organic managed rice fields ensuring the objectivity of the selected stations.

AUTHORS CONTRIBUTION

A.S.K. collected, analyzed the data, and wrote the manuscript. R.N.B. analyzed the data and wrote the manuscript. H.P. designed the research and supervised all the process.

ACKNOWLEDGMENTS

We thank the University of Jember for Penelitian Dosen Pemula (PDP) grant. We also thank Mr. Yusnan in Kemiri and Tani Jaya Dua farmer groups in Sumberjambe, Jember, for their permission to access the sampling stations. The author would like to thank Indah Dwi Lestari and Chaidzar Ali Paryoga for their invaluable assistance in the identification process. The author also thanks Moh. Ilham for invaluable supports in the field and Purnomo in Brawijaya University for his advice in the process of identification.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the content and there is no financial interest to report. We certifiy that the manuscript is original work, and is not under review at any other publication.

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