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# BENTHIC MACROINVERTEBRATES AND BIOLOGICAL EVALUATION OF WATER QUALITY AT YOUNGHEUNG STREAM IN KOREA

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## ABSTRACT

Benthic macroinvertebrates are commonly used as useful biological indicators in water quality. In the present study, spatial distribution analysis of benthic macroinvertebrates and biological assessment of water quality were investigated at four different sites using benthic macroinvertebrate at Youngheung stream in South Korea. From the four seasons survey, a total of 43 macrobenthic species belonging to five phyla, seven classes, fourteen orders and 34 families were identified. The value of dominance index (DI) was varied from 0.306 (St. D) to 0.342 (St. A) with a mean of 0.333. Beck-Tsuda's Biotic Index (BI) was varied from 30 (St. D) to 36 (St. A) with a mean of 33.5. Total ecological score of benthic macroinvertebrate community (TESB) was 72.8. Average ecological score of benthic macroinvertebrate community (AESB) was 2.659. Benthic macroinvertebrate index (BMI) was 62.610. Mean value of geometric density was 1.378. Mean Shannon-Weaver index (H´) at the upper region (St. A) was higher than those of low region (St. D). The Simpson Index (C) was not shown significant differences ($p < 0.05$). Berger-Parker's index (BPI) was varied from 0.166 (St. D) to 0.256 (St. B). Downstream, there are fewer pollution-sensitive invertebrates and more resistant species. In this study, the evaluation of water quality using invertebrates was well reflected.

**Keywords:** Beck-Tsuda's Biotic Index (BI), benthic macroinvertebrate index (BMI), dominance index (DI), Youngheung stream, water quality.

## INTRODUCTION

Much of the water taken by humans from streams and aquifers never returns to its source. For example, over 80% of the agricultural water applied to crops evaporators (Chiras, 1998). Consequently, many rivers flows at a fraction of their natural rates during high-use seasons. This reduces populations of aquatic species and is increasingly becoming a priority policy issue at most countries. Water that is returned to surface water supplies is often polluted with agricultural pesticides and fertilizer or waters from homes and factories.

Water pollutants come from numerous natural and anthropogenic sources. Anthropogenic sources are the most important because they tend to be much more localized and thus contribute significantly to the deterioration of local waterways. Because water respects no boundaries, pollutants produced in one country often end up in another's water supply.

Biomonitoring is defined as the systematic use of response of biological variables to evaluate changes in the environment, usually caused by anthropogenic actions (Rosenberg & Resh, 1993; Buss et al., 2003). The organisms considered bioindicators are chosen for their sensitivity or tolerance to the presence of stressors (Bonada et al., 2006). Looking many water quality assessments based on biological indicators have been developed over the past tens of year, of which about 60% are biotic ones based on macroinvertebrate analysis (De Pauw & Hawkes, 1993). Amongst aquatic organisms that can be used for bioassessment, macroinvertebrates have proved to be excellent indicators for the quality of freshwater stream habitats (Hawkes, 1997). As water quality and habitat conditions change, the benthic macroinvertebrate community also changes. Benthic macroinvertebrate is ubiquitous and can be affected by environmental perturbations in different types of aquatic systems. Many species among them are responsive to pollution and abrupt changes in their surroundings. Unlike fish and other vertebrates, benthic macroinvertebrates are less mobile and are unable or unlikely to escape the effects of sediment and other pollutants that diminish water quality. Benthic macroinvertebrates represent a diverse group of aquatic animals. Their sedentary nature allows effective spatial analyses of pollutants or disturbances.

Biotic indices are numerical expressions combining a quantitative measure of species diversity with qualitative information on the ecological sensitivity of individual taxa, among others (Czerniawska-Kusza, 2005). The saprobic system has been developed to provide a numerical index - the saprobic index. This has resulted in different saprobic indices of different complexities (Sladecek, 1973). The main advantage of the saprobic system is that it includes a wide range of taxa and communities and is thus applicable to all types of rives. However, specific critics on the system are the demanding identifications required - to species level - which makes it cost and time consuming (Carter & Resh, 2001; Bonada et al., 2006). Diversity indices use three components of community structure to describe the response of a community to the quality of its environment: namely, richness (number of species present), evenness (uniformity in the distribution of individuals among the species) and abundance (total number of organisms present). Three diversity indices are frequently applied (on an individual basis) in stream studies: the species richness, the total diversity and the evenness index (Shannon and Weaver, 1963; Hill, 1973).

This study focus on streams because the use of macroinvertebrates as biological indicators is better established in the lotic systems on Youngheung stream in Korea. In addition, this study evaluates on the application of saprobic extent and other ecological biodiversity methods for the assessment of river water quality.

## METHODOLOGY

### Surveyed regions

This study was carried out on Youngheung stream, located at (upper region: 35°399′564″N/128°169′024″E, low region: 35°398′990″N/128°125′691″E), located at Hapcheon-gun, Gyeongsangnam-do province in Korea (Fig. 1). Uplands are usually no higher than 400m. Flood plains of this river are usually very fertile agricultural areas and out sides of this river consist of a mosaic of agricultural fields.

### Sampling procedures

The study was carried out for a period of four seasons. Four sampling stations of the water body were selected randomly integrating the whole water body into one and the stations were denoted as the St. A, St. B, St. C, and St. D (Fig.1). Each station covers an area of about 100m length irrespective of breadth of water body.

Benthic macroinvertebrates are collected systematically from all available in-stream habitats by kicking the substrate or jabbing with a D-frame dip net (0.3 m wide and length, 500 µm mesh). A total of 20 jabs (or kicks) are taken from all major habitat types in the reach, resulting in sampling approximately 3.1 ㎡ of habitat. Submerged macrophytes are seasonal in their occurrence and may not be a common feature of many streams, particularly those that are high-gradient. All samples were combined into a single sample and preserved in the field with 70% ethanol. In the laboratory, specimens were rinsed in 500 μm mesh sieves and large organic materials were removed. All organisms from the sorted sample were identified to the lowest possible taxonomic taxon based on accepted list of names for a particular group to ensure their validity and use (Shin, 1993; McCafferty 1981; Kawai 1985; Merrit & Cummins 1996; Yoon, 1995; Won, 2005). Those specimens were assigned to operational taxonomic units (OTUs).

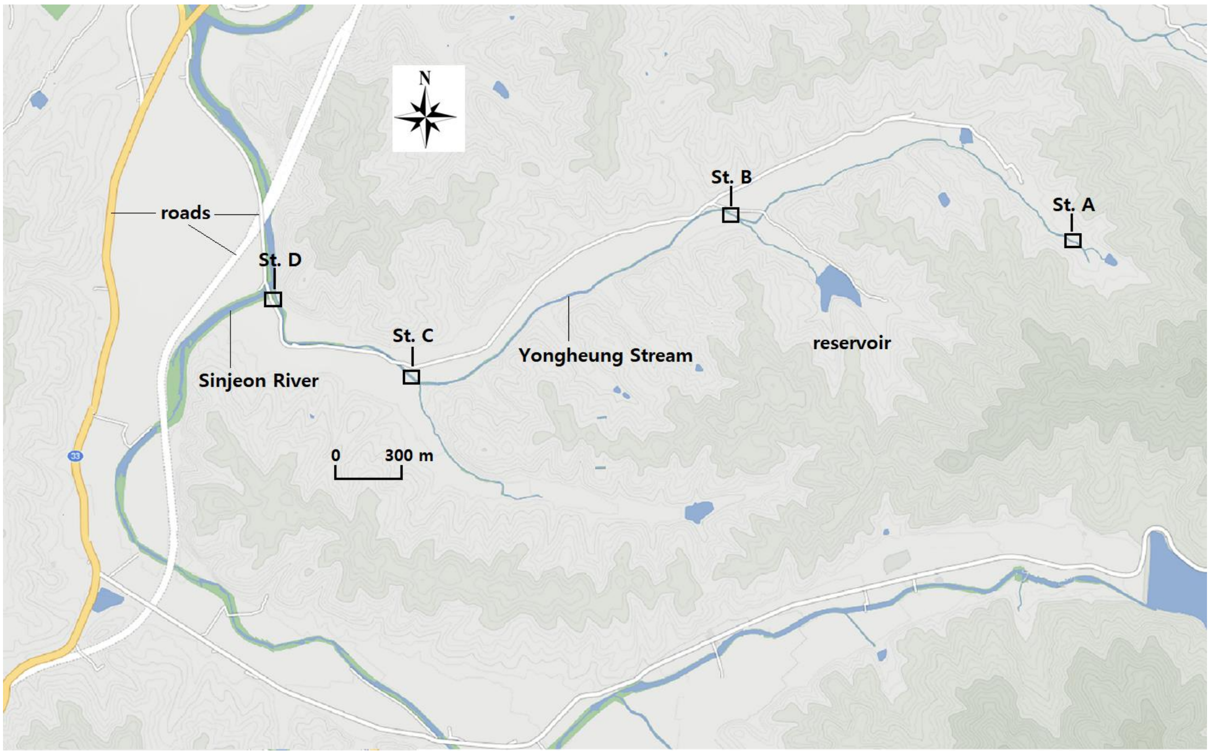

Fig. 1. Map showing locations of sampling sites along the Youngheung stream.

## Water evaluation

Many indices only account for categorical diversity between subjects or entities. Dominance index (DI) was calculated using the formula, DI=(N1+N2)/N, where N1 is number of individuals in first dominant species and N2 is number of individuals in second dominant species.

Biotic Index (BI) is based on categorizing macroinvertebrates into categories depending on their pollution. One of the comprehensive of these indexes is the one proposed by the Hilsenhoff (1977) formula: $BI = \Sigma\, n_i\, a_i/N$. Where $n_i$ is the number of specimens in each taxonomic group, $a_i$ is the pollution tolerance score for that taxonomic group, and N is the total of organisms in sample. Macroinvertebrates are given a numerical pollution tolerance score ($a_i$) ranging from 0 to 5. Another community index, Beck-Tsuda's Biotic Index (BI) (Tsuda, 1964), is based on weighted community indices. Total ecological score of benthic macroinvertebrate community (TESB) was calculated by the method of Kong et al. (2018). Average ecological score of benthic macroinvertebrate community (AESB) was calculated by the method of Kong et al. (2018). AESB is the same formula as Hilsenhoff's BI.

**Table 1. Classification scheme of the environmental quality score of benthic macroinvertebrates according to the indicator table from NIER (2016)**

| Qi | Saprobic value | Saprobity | $BOD_{5(mg/L)}$ |
|---|---|---|---|
| 5 | ≤0.1 | Xenosaprobic | ≤1 |
| 4 | >0.1 ~ 1.0 | Oligosaprobic | >1 ~ 2 |
| 3 | >1.0 ~ 2.0 | β-mesosaprobic | >2 ~ 4 |
| 2 | >2.0 ~ 3.0 | α-mesosaprobic | >4 ~ 8 |
| 1 | >3.0 | Polysaprobic | >8 |

**Table 2. The scheme of ESB according to the phase of environmental quality (NIER, 2002)**

| ESB | Environmental condition | Area determination | Water quality |
|---|---|---|---|
| 81< | Very satisfactory | First priority water | I |
| 61-80 | Satisfactory | Priority protection water | I |
| 41-60 | Some satisfactory | Protection water | II |
| 26-40 | Some defectiveness | Improvement water | II |
| 13-25 | Defectiveness | Priority improvement water | III |
| <12 | Very defectiveness | First priority improvement water | IV-V |

An analysis was conducted of the Benthic Macroinvertebrate Index (BMI), a biometric assessment technique using the large scale animals that appeared at each station (Kong et al. 2012).

**Table 3. Classification of benthic macroinvertebrates index (BMI) for the evaluation of river status (Kong et al., 2018)**

| Class | BMI | Status | |
|---|---|---|---|
| | | Diversity | Disturbance sensitive taxa |
| A | 80≤-100 | Least signs of alteration from undisturbed levels | Least signs of alteration from undisturbed levels |
| B | 65≤-80 | Slight alteration from undisturbed levels | Slight alteration from undisturbed levels |
| C | 50≤-65 | Significantly lower than alteration from undisturbed levels | Significantly lower than alteration from undisturbed levels |
| D | 35≤-50 | Very low species richness | Most of the sensitive taxa are absent |
| E | 0-35 | Several species are present or not | Sensitive taxa are absent. Insensitive taxa shows high abundance or not |

Arithmetic mean of relative abundance indices. The species-specific densities (Dij) are scaled by dividing the time series for each species by its estimated density at the initial time point (Buckland et al., 2005).

The Shannon-Wiener Index (H′), adopted from information theory, is currently one of the most widely used diversity measures (Shannon & Weaver, 1998). The basic formula is:

$$H' = -\Sigma\, pi \ln pi$$

Where *pi* is the number of individuals in the *i*th species and N equals the total number of individuals in the sample. The Simpson Index (C), with values ranging from 0 to 1, is the probability that if two selections are made randomly from a collection of organisms, they will be individuals of the same species. This index is calculated as follows:

$$C=1-\sum_{i=0}^{s}\left(\frac{ni}{N}\right)^2$$

Where *ni* is the number of individuals in the *i*th specie, N equals the total number of individuals in the sample, and s equals the total number of samples in the sample. Determine the average species diversity indexes for each site and compare.

$N1 = e^{H'}$

$N2 = 1/\lambda$

Where λ (Simpson's index) for a sample is defined as

$\lambda = \sum ni(ni-1)/ N(N-1)$

The species richness of animals was calculated by using the method, Berger-Parker's index (BPI) and Margalef's indices (R1 and R2) of richness (Magurran, 1988). BPI = *N*max/N where *N*max is the number of individuals of the most abundant species, and N is the total of individuals of sample. Species evenness is a measure of biodiversity which quantifies how equal the community is numerically. Evenness indices (E1~E5) was calculated using important value index of species (Pielou, 1966; Hill, 1973).

**Table 4. Representative benthic macroinvertebrate taxa in Korean streams according to saprobic value based on Shannon - Wiener's species diversity index (H') (Bae and Lee, 2001)**

| H' | Saprobitic categories | Representative benthic macroinvertebrate taxa |
|---|---|---|
| 0-0.9 | Polysaprobic | Tubificidae |
| 1-1.9 | α-mesosaprobic | *Chironomus yoshimatsui* - group |
| 2-2.9 | β-mesosaprobic | *Hydropsyche kozhantschikovi, Uracanthella rufa, Epeorus latifolium* |
| 3-4.5 | Oligosaprobic | *Drunella*, Plecoptera, *Rhyacophila* |

## RESULTS

From the four seasons survey, a total of 43 macrobenthic species belonging to five phyla, seven classes, fourteen orders and 34 families were identified (Table 5). Only two species of benthic invertebrates belonging to Platyhelminthes, one species under Nematomorpha, four species under Mollusca, six species under Annelida, and thirty species under Arthropoda were found. Dominant species was *Choroterpes* (*Euthraulus*) *altioculus* which exhibited greatest individuals (232) and second dominant species was *Anopheles* sp. (102 individuals) (Table 6). Dominant taxa at St. A was *Choroterpes* (*Euthraulus*) *altioculus*, followed by *Ecdyonurus kibunensis*. St. B was *Choroterpes* (*Euthraulus*) *altioculus*, followed by *Hydropsyche* KUa. St. C was *Anopheles* sp., followed by *Choroterpes* (*Euthraulus*) *altioculus*. St. D was *Culicini* sp., followed by *Anopheles* sp.

**Table 5. Species composition for invertebrates in the studied areas**

| Phylum | Species | % | Individuals | % |
|---|---|---|---|---|
| Platyhelminthes | 2 | 4.7 | 11 | 0.9 |
| Nematomorpha | 1 | 2.3 | 2 | 0.2 |
| Mollusca | 4 | 9.3 | 32 | 2.5 |
| Annelida | 6 | 14.0 | 73 | 5.7 |
| Arthropoda | 30 | 69.8 | 1170 | 90.8 |
| Total | 43 | 100.0 | 1288 | 100.0 |

**Table 6. First and second dominant species for invertebrates in the studied areas**

| Sites | Dominant species | Subdominant species | DI | Mean |
|---|---|---|---|---|
| St. A | *Choroterpes* (*Euthraulus*) *altioculus* Kluge | *Ecdyonurus kibunensis* Imanishi | 0.342 | 0.333 |
| St. B | *Choroterpes* (*Euthraulus*) *altioculus* Kluge | *Hydropsyche* KUa | 0.341 | |
| St. C | *Anopheles* sp. | *Choroterpes* (*Euthraulus*) *altioculus* Kluge | 0.341 | |
| St. D | *Culicini* sp. | *Anopheles* sp. | 0.306 | |
| Total | *Choroterpes* (*Euthraulus*) *altioculus* Kluge | *Anopheles* sp. | 0.281 | |

The value of dominance index (DI) was varied from 0.306 (St. D) to 0.342 (St. A) with a mean of 0.333 (Fig. 2). DI was not significantly different among the four regions ($p<0.05$).

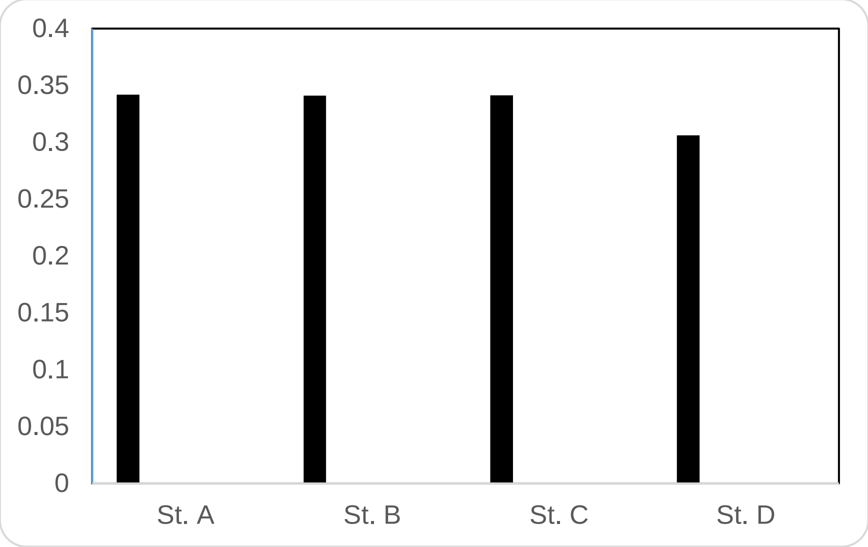

Fig. 2. Variability of the dominance indices (DI) of macroinvertebrate species in the benthos of Youngheung stream.

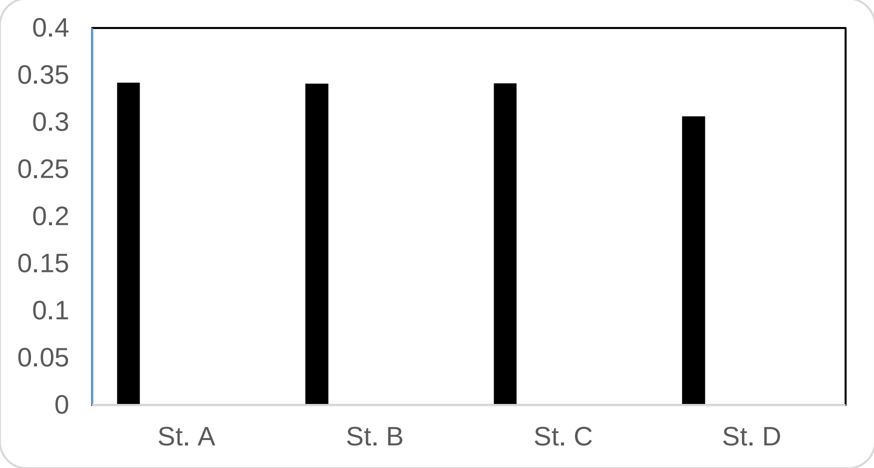

Fig. 3. Variability of the Beck-Tsuda's Biotic Index (BI) of macroinvertebrate species in the benthos of Youngheung stream.

Beck-Tsuda's Biotic Index (BI) was varied from 30 (St. D) to 36 (St. A) with a mean of 33.5

(Fig. 3). BI was not shown significantly different among the four regions ($p < 0.05$).

Total ecological score of benthic macroinvertebrate community (TESB) was varied from 58 (St. D) to 85 (St. A) with a mean of 72.8 (Table 7). Average ecological score of benthic macroinvertebrate community (AESB) was varied from 2.148 (St. D) to 3.269 (St. A) with a mean of 2.659. Benthic macroinvertebrate index (BMI) was varied from 40.410 (St. D) to 83.363 (St. A) with a mean of 62.610.

**Table 7. Total ecological score of benthic macroinvertebrate community (TESB), average ecological score of benthic macroinvertebrate community (AESB), and benthic macroinvertebrate index (BMI) for the evaluation of river status (Kong et al., 2018)**

| Station | TESB | AESB | BMI |
|---|---|---|---|
| A | 85 | 3.269 | 83.363 |
| B | 77 | 2.852 | 76.814 |
| C | 71 | 2.367 | 49.453 |
| D | 58 | 2.148 | 40.410 |
| Mean | 72.8 | 2.659 | 62.610 |

In this paper, the density of each species in the group and summing across species was shown in figure 4. The value of geometric density was varied from 1.214 (St. C) to 1.529 (St. D) with a mean of 1.378.

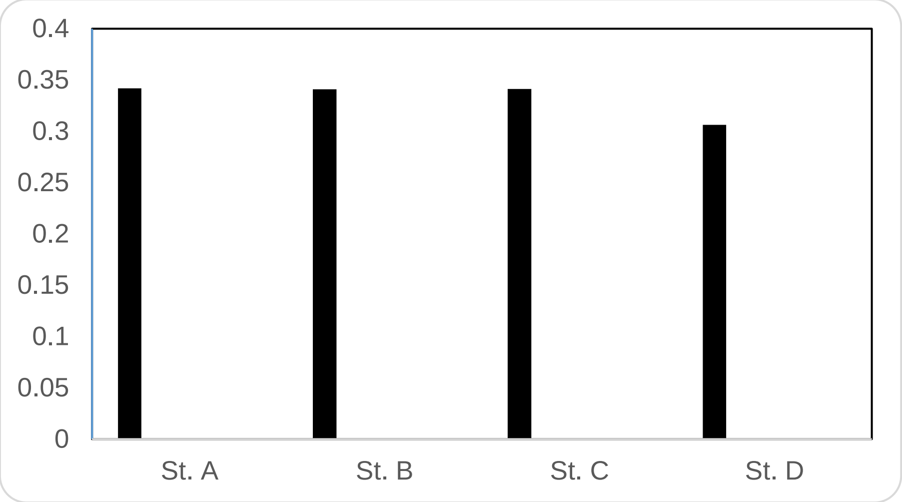

Fig. 4. The geometric mean of macroinvertebrate species at Youngheung stream.

The density of each species in the group and summing across species was shown in figure 4. The value of geometric density was varied from 1.214 (St. C) to 1.529 (St. D) with a mean of 1.378.

In order to assess macro-scale spatial variability of the animal community at Youngheung stream, I analyzed distributions of species richness, diversity, and evenness of large taxonomic groups as well as four station compositions along a geographic distance (Table 8). Mean Shannon-Weaver index (H′) of diversity was varied from 1.553 (St. D) to 2.261 (St. A). H′ at the upper region (St. A) was higher than those of low region (St. D). The Simpson Index (C) was not shown significant differences ($p < 0.05$).

Berger-Parker's index (BPI) was varied from 0.166 (St. D) to 0.256 (St. B). Richness indices for animal taxa were also varied among the stations and seasons. Although richness indices (R1-R2) for four stations were different from each other, there were not shown significant differences ($p < 0.05$). Evenness indices (E2-E4) except E5 were different from each other, there were shown significant differences ($p > 0.05$). E2-E4 at the upper region (St. A) were higher than those of low region (St. D).

**Table 8. Biological diversity index for invertebrates in the studied areas**

| Indices | St. A | St. B | St. C | St. D |
|---|---|---|---|---|
| Richness | | | | |
| BPI | 0.238 | 0.256 | 0.238 | 0.166 |
| R1 | 4.198 | 4.545 | 4.762 | 4.365 |
| R2 | 1.323 | 1.546 | 1.644 | 1.484 |
| Diversity | | | | |
| H' | 2.261 | 1.888 | 1.705 | 1.553 |
| C | 0.918 | 0.913 | 0.918 | 0.972 |
| N1 | 9.597 | 6.606 | 5.500 | 4.727 |
| N2 | 12.424 | 11.725 | 14.307 | 38.095 |
| Evenness | | | | |
| E1 | 0.694 | 0.573 | 0.512 | 0.477 |
| E2 | 0.369 | 0.245 | 0.196 | 0.182 |
| E3 | 0.343 | 0.216 | 0.167 | 0.149 |
| E4 | 1.295 | 1.775 | 2.601 | 8.059 |
| E5 | 1.329 | 1.914 | 2.957 | 9.952 |

## DISCUSSION

Benthic macroinvertebrates have been used for decades as biological indicators of river and stream health. Several types of index can be generated such as diversity or biotic indices. The Shannon-Weaver index, the Simpson's diversity and Pielou's evenness index, others, are well-known examples. These indices have been used extensively for aquatic biota and even more extensively for terrestrial (Abbasi & Abbasi, 2011). But these indices overlook many important variable and tend to oversimplify the natural systems which are, in fact, highly complex (Karr, 1981). In contrast, biotic indices are assigned a sensitivity weighing, or scores based on the tolerance or sensitivity of that taxon to particular pollutants. Evaluations for Water quality at Youngheung stream according to saprobic value based on Shannon - Wiener's species diversity index (H') (Bae and Lee, 2001) were α-mesosaprobic (St. B, St. C, and St. D) and β-mesosaprobic (St. A) (Table 4). The saprobic index and ESB for the evaluation of Youngheung stream status revealed that water quality at St. A was I (oligosaprobic) which means very satisfactory and first priority water (Table 2). Environmental status at St. B and St. C was satisfactory and area determination was priority protection water. However, water quality at D was II (β-mesosaprobic). Benthic macroinvertebrate index (BMI) was varied from 40.4 (St. D) to 83.4 (St. A) with a mean of 62.5. Classification of benthic macroinvertebrates index (BMI) for the evaluation of river status at St. A was least signs of alteration from undisturbed levels (Table 3). The BMI evaluation of river status at St. B was slight alteration from undisturbed levels. The BMI evaluation of river status at St. C and St. D was Very low species richness and most of the sensitive taxa were absent. The evaluation of river status at St. C and D was α-mesosaprobic and most of the sensitive taxa are absent.

The structure of macroinvertebrate communities depends on abiotic and biotic factors that vary across spatial scales from regional to habitat-specific and is discussed in detail by Lamoureaux et al. (2004), Malmquist (2002), and Kenney (2009).

Biological factors on water quality in this area are closely related to agricultural management. As the aging of farmers makes it difficult to prepare weeds or natural composts, the elderly use herbicides or chemical fertilizers more than ever before. Agricultural pollution can originate from either a point source (e.g. from a slurry store) or diffusely (e.g. run off from larger areas of farmland). As diffuse pollution can arise from the contributions of many smaller sources (e.g. fields on many farms), it is often difficult to attribute it to a specific sector or activity and the impacts of pollution can occur some distance from the source, for example, as nutrient levels increase downstream. Therefore, downstream of these streams are more contaminated than upstream. Downstream, there are fewer pollution-sensitive invertebrates and more resistant species. In this study, the evaluation of water quality using invertebrates was well reflected.

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