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PRIMARY RESEARCH PAPER

The effect of organic pollution on the abundance and distribution of aquatic oligochaetes in an urban water basin, Taiwan

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Abstract Aquatic oligochaetes are abundant in polluted areas and are, therefore, commonly used as bioindicators to study organic pollution in rivers and streams. In order to develop a species-level oligochaete biotic index to reflect the River Pollution Index (RPI) in the Taichung Water Basin in Taiwan, we conducted a systematic sampling scheme to collect aquatic oligochaetes from the sediment samples of watercourses in the Taichung Water Basin, Taiwan. We evaluated the relationships between aquatic oligochaetes and the sewage pollution using statistical methods. The distribution of aquatic oligochaetes in relation to environmental variables, such as water quality and sediment characteristics of the regional urban contaminated streams was expressed by Canonical Correspondence Analysis (CCA). We identified 17 species of aquatic oligochaetes (Annelida, Clitellata) including 3 species of Tubificidae, 13 species of Naididae, and 1 species of Enchytraeidae from the watercourses of an urban region in the Taichung Water Basin in Taiwan, during the summer and winter of 2005 and 2006. A positive correlation was found between the total abundance of aquatic oligochaetes and the RPI ($r = 0.58$, $P < 0.05$). However, only population density of the most abundant tubificid, *Limnodrilus hoffmeisteri*, increased with increasing RPI values and a significantly negative correlation was found between the population density of the naidid, *Nais communis*, and RPI values. The results of CCA indicated that certain naidids, such as *Aulophorus furcatus* and *Allonais gwaliorensis* also tolerated extremely polluted environments in upper stream or stony habitats, implying that tubificids should not be the sole representation of simple biotic indices but should also include pollution-tolerant naidids. We found that the community structure of aquatic oligochaetes was influenced by short-term variations in microhabitat rather than according to seasonal factors in our study region. The results proved that aquatic oligochaetes were sensitive enough to provide a supplement for the regional urban pollution assessment applications for biotic indicators at the species-level.

Keywords Aquatic oligochaete · River pollution · Multivariate analysis · Habitat preferences · Pollution assessment · Indicator species

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Introduction

Aquatic oligochaeta (Clitellata) have been universally applied on bioassessment assays, as bioindicators to reflect the organic pollution in rivers and streams. The numbers or proportion of specific species, such as

Limnodrilus hoffmeisteri and *Tubifex tubifex* are often used as symbolic indicators for organic pollution, due to their dominant status in polluted areas (Brinkhurst & Jamieson, 1971; Aston, 1973).

In order to monitor the pollution status of an urban watercourse, the Environmental Protection Administration of Taiwan has requested a proposal for a rapid bioassessment protocol of rivers and streams that would be suitable for Taiwan. Commonly, the family-level biotic index (FBI) (Hilsenhoff, 1988) is used for research on benthic macroinvertebrates. However, in some polluted urban areas, the family indices might not be sensitive enough to reflect the regional variance. Plafkin et al. (1989) and Bode et al. (1996) developed a series of modified biotic indices that extend to the species-level, and contain hundreds of listed species. This could be a good reference for checking the tolerance values of certain specific species. However, these checklists were established for North America and might not be suitable for the subtropical environment in Taiwan. Therefore, in order to formulate a feasible monitoring system, it is necessary to establish a detailed ecological account of the local species.

Recently, many biologists have applied multivariate statistical methods to study the relationships between benthic organisms and abiotic factors. Ordination techniques are used to describe the species–environment associations of aquatic oligochaetes (Martínez-Ansemil & Collado, 1996; Verdonschot, 1999, 2001; Schenková et al., 2001; Nijboer et al., 2004), and to identify the factors that might have an influence on habitat preferences for each taxon. In addition, it is a practical way to understand the tolerance range of specific species among some given environmental variables.

Cheng (1995) and Hsieh et al. (1998) conducted detailed surveys at Tanshui River, Keelung River, and the mangroves near their estuary of Taiwan and reported five freshwater oligochaete species in total. Erséus & Hsieh (1997) described five species of estuarine Tubificidae collected from northern Taiwan, including *Limnodrilus hoffmeisteri* and *Branchiura sowerbyi*, which were categorized as freshwater forms. Shen et al. (2005) reported a new record of *Eiseniella tetraedra* (Lumbricidae) collected in a mountain creek. However, the diversity and distribution of aquatic oligochaetes in lowland Taiwan waters are to date undocumented. Yu et al. (1995) studied the correlations of pollutants and benthic organisms in the Ellren Stream, Southern Taiwan, but the whole oligochaete class was generalized as "*Tubifex* sp." in their report. Lin et al. (2005) studied the life history of *Limnodrilus hoffmeisteri* in the Dali Stream and referred to the existence of some relationships between its population and environmental factors. However, a detailed habitat description of oligochaetes remains unreported.

The purpose of this study is to evaluate the relationships between the population density of aquatic oligochaetes and the sewage pollution in the Taichung Water Basin. Furthermore, we seek to determine if any further relationships exist between the aquatic oligochaete community and environmental factors, through the application of multivariate statistical methods.

Materials and methods

Study sites

The study area and 14 sampling site locations are listed in Fig. 1. Sampling sites were located in the Taichung Water Basin, Central Taiwan, and inside the drainage system of the Dali Stream, with the exception of the southernmost site in Nantou City. These streams and watercourses are the network water system inside Taichung City and its satellite towns, serving a population greater than one million. The system receives domestic sewage from urban areas, because a complete sanitary sewer system has not been established for the area. According to the statistics of the Environmental Protection Administration of Taiwan, the lower reaches of the Dali Stream have been rated as moderately to heavily polluted over the last 30 years.

Field sampling and identification

Sampling took place during the summer of 2005 (July and August) and winters of 2005 and 2006 (December and January respectively). At each site, three samples were collected with a PVC-made tubular corer (5 cm in diameter), inserted into the sediment at a depth of about 10 cm. At sites with rocky or hard substrata, a small shovel and a netted scoop were required to scrape the sediment. We sieved the


No.	Site name	Distance from estuary (km)
1	Wu Niou Lan Creek	51.9
2	Feng Jia Bridge	44.8
3	Heng Keng	44.9
4	Chang Ho Bridge	39.5
5	Chang Fu Bridge	36.2
6	Niao Chu Wei Park	25.8
7	Kuo Kuang Bridge	25.6
8	Lyu Ditch	26.3
9	Da Li Bridge	31.3
10	Si Nan Bridge	23.3
11	Wu Bridge	31.0
12	Chao Yang Ditch	21.4
13	Fa Tzisih Bridge	21.3
14	Jyun Gong Bridge	47.7

Fig 1 A map of the sampling site locations (right). The numbers marked on the map correspond to the list that provides the full names of each site and the distance from the estuary

sediment through a 0.25-mm screen. Oligochaetes remaining on the screen were sorted under a stereomicroscope, then fixed in 10% formalin for one day, and preserved in 80% alcohol thereafter.

Most oligochaetes were identified to genus level according to the taxonomic key provided by Brinkhurst & Gelder (2001) and Strayer (1990) and counted under a stereomicroscope. All further identification to the species level was conducted using a classic optical microscope, according to the key offered by Brinkhurst & Jamieson (1971), Brinkhurst & Wetzel (1984), and Timm & Veldhuijzen van Zanten (2002).

Environment variables

The pollution characteristics of water quality, including dissolved oxygen (DO), biochemical oxygen demand (BOD_5), ammonia nitrogen (NH_4^+–N), and suspended solids (SS) for each sampling site were provided by the monthly communiqué of the regional bureau of environmental protection. These four values were used to calculate the River Pollution Index (RPI), a synthetic index for rating the organic pollution of rivers defined by the Environmental Protection Administration of Taiwan (Table 1).

We also recorded several habitat conditions such as water pH, current velocity, percentage of vegetation coverage, and other descriptive characteristics (ex. the presence/absence of big cobbles or filamentous algae) upon sampling.

Sediment samples were dried and sieved through a series of sieves of different mesh size and then weighed to determine grain size distribution. The mean grain size and sorting index (σ) of each sediment sample was calculated by using the GRADISTAT

Table 1 River Pollution Index criteria and the pollution classes defined by the Environmental Protection Administration of Taiwan

Parameters	Unpolluted	Slightly polluted	Moderately polluted	Heavily polluted
DO (mg/l)	>6.5	4.6–6.5	2.0–4.5	<2.0
BOD (mg/l)	<3.0	3.0–4.9	5.0–15.0	>15.0
SS (mg/l)	<20	20–49	50–100	>100
$NH4^{+}$–N (mg/l)	<0.50	0.51–0.99	1.00–3.00	>3.00
Score	1	3	6	10
Average score (RPI)	<2.0	2.0–3.0	3.1–6.0	>6.0

program (Blott & Pye, 2001). Total organic matter content of sediments was determined by the loss-on-ignition method (Heiri et al., 2001) at a temperature of 550°C.

Data analysis

The abundance of oligochaetes were expressed as densities (individuals per m^2), equivalent to the density within the cross-section of the sampling corer or the scraping area, and transformed into logarithm by (log(x + 1)). Linear regressions were used to evaluate the relationship between RPI and the abundance of oligochaetes, and to predict the threshold values for each pollution class. In order to distinguish the most representative environmental variables and trends of habitat distribution among different sampling sites, principal component analysis (PCA) was used to draw an ordination diagram indicating sites and environmental variables (using the variance–covariance matrix). The similarity (Euclidean distance) of community composition between each site in different seasons was displayed by using non-metric multidimensional scaling (n-MDS). Linear regressions, n-MDS, and PCA analysis were performed using PAST programs (Hammer et al., 2001).

We also evaluated the relationship between the population abundance of oligochaetes and environmental variables by applying canonical correspondence analysis (CCA), offered by the PC-ORD4 program (McCune & Mefford, 1999). The program also drew species score relationships with environmental variables on an ordination diagram. A 999-times Monte Carlo permutation test was applied for verifying the statistical significance of species–environment correlations.

All abiotic parameters were normalized by means and standard deviation prior to applying the multivariate statistics (PCA, n-MDS, and CCA).

Results

Species composition

We collected 17 species of aquatic oligochaetes, including 3 species of Tubificidae, 13 species of Naididae, and 1 species of Enchytraeidae, in the Taichung Water Basin. Some species could only be classified to genera level (Table 2). Among the 6237 total specimens collected, the percentage abundance of *L. hoffmeisteri*, *Aulophorus furcatus, Pristina synclites*, *Dero digitata* and *Branchiura sowerbyi* were 68.8%, 11.2%, 7.1%, 2.9%, and 2.5% respectively. These species were the most dominant aquatic oligochaetes in the watercourses of Taichung Basin.

Although our study is the first record of many taxa in Taiwan, most were cosmopolitan and expected to appear in Taiwan according to the list presented by Timm (1999). A few species, such as *Allonais gwaliorensis*, *Chaetogaster diaphanus*, and *Marionina* sp., were found only in unique sites, including *Stylaria fossularis* specimens collected only from an irrigation canal outside of the 14 regular sampling sites. Interestingly, the cosmopolitan species *Tubifex tubifex* was not found here although it has been informally documented in some local literature.

Averages of population density, taxa numbers, and diversity (Shannon's H) of oligochaetes were slightly higher in winter, but showed no statistical difference between the two seasons (paired *t*-test, $P > 0.1$). We also compared the species composition site-to-site using the paired Hotelling's T^2 test. Results indicate

Table 2 A list of oligochaete species and abbreviations collected from the Taichung Water Basin

Species name	Abbr.
Family Naididae	
*Nais communis** Piguet, 1906	Ncm
*Allonais gwaliorensis** Stephenson, 1920	Agl
*Aulophorus furcatus** Müller, 1773	Afc
*Dero digitata** Müller, 1773	Ddt
*Dero dorsalis** Ferronière, 1889	Dds
Dero sp.	Dsp
*Pristinella jenkinae** Lastočkin, 1927	Pjk
*Pristina synclites** Stephenson, 1925	Psn
*Pristina longiseta** Ehrenberg, 1828	Pls
*Chaetogaster diastrophus** Gruithuisen, 1828	Cdt
*Chaetogaster diaphanus** Gruithuisen, 1828	Cdp
Stephensoniana trivandrana * Aiyer, 1926	Sst
*Stylaria fossularis** [a] Leidy, 1852	Sfs
Family Tubificidae	
Limnodrilus hoffmeisteri Claparède, 1862	Lhf
*Aulodrilus pigueti** Kowalewski, 1914	Apg
Branchiura sowerbyi Beddard, 1892	Bsw
Family Enchytraeidae	
Marionina sp.*	Msp

Species names marked with an asterisk are the first records in Taiwan

[a] Specimens were collected from an irrigation canal outside of the 14 regular sampling sites

no significant difference (P = 0.793) between summer and winter. As can be seen from the n-MDS diagram, the distribution of summer and winter dots largely overlapped (Fig. 2). Therefore, since the seasonal trends in each site were discordant, the community composition of oligochaetes in the Taichung Water Basin is likely influenced by complex habitat conditions rather than by seasonal variation alone.

Habitat characteristics of sampling sites

With the exception of two sites (No.1&3) located at the upstream reach near the piedmont, all other sites were rated as moderately to heavily polluted during both summer and winter. Although the Heng Keng Creek (No.2) is located at an upstream reach, it was classified as a polluted site, likely due to the nearby tourist resorts and local residents that discharge sewage directly into the watercourse. The RPIs indicate that the water was

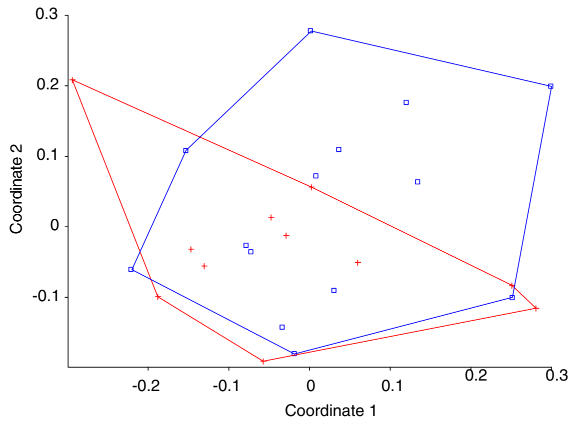

Fig 2 An n-MDS diagram (n = 26, stress = 0.24) shows the similarity of species composition among sampling sites indicated by the distances between dots (crosses: summer data; squares: winter data)

significantly more polluted in winter than in summer (paired t-test, $P < 0.05$), probably due to the winter dry season in Central Taiwan.

The bi-plot diagram derived from PCA analyses shows the sampling site distribution pattern on the gradient of environment factors (Fig. 3). Vegetation coverage proved to be the most important factor on the first PCA component (axis 1), and correlates negatively with current velocity and gravel. This result reflects the fact that macrophytes occur in finer sediments where there is less gravel and cobble. RPI is another emblematic variable in axis 1, as it correlates negatively with pH and distance from

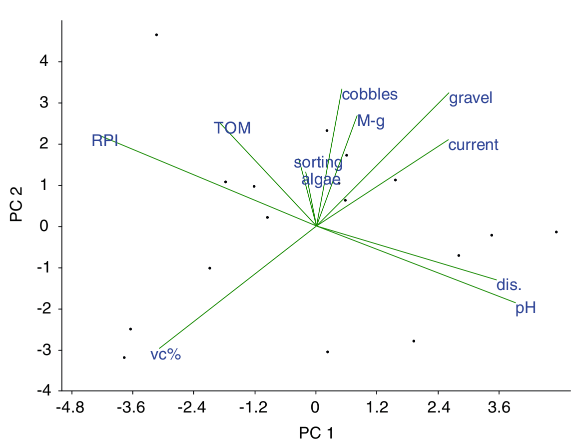

Fig 3 An ordination bi-plot of PCA shows all 14 sampling sites (dots) and environmental variables (vector lines). Abbreviations for each variable can be found in *Table* 3

estuary. This implies that downstream water is more acid and polluted than upper stream water. Total organic matter contents and cobbles both positively correlate in the second PCA component (axis 2), indicating that sediments are enriched with organic matter in cobbled and polluted riverbeds. The percentage of variance was 27.9%, 23.7%, and 15.3% for axis 1, 2, and 3, respectively (Table 3).

Organic pollution and oligochaetes population density

A positive correlation ($r = 0.58$, $P < 0.05$) was found between the density of aquatic oligochaetes and the River Pollution Index (Fig. 4). We used the regression equation: $\text{RPI} = 1.24 \times \text{T}–0.91$, where T represents logarithmic population density. According to this equation and the definition of RPI classes, oligochaetes occur below 200 idv./m^2 in unpolluted waters, 200–1,400 idv./m^2 in slightly unpolluted waters, 1,400–370,000 idv./m^2 in moderately polluted waters, and exceed 370,000 idv./m^2 in heavily polluted waters where the RPI is greater than 6.

However, only the population density of *L. hoffmeisteri* increased significantly with increasing RPI values ($r = 0.43$, $P < 0.1$). Negative correlations were found between RPI values and the population density of several species, while only a minor species, *Nais communis*, showed a significant correlation ($r = –0.44$, $P < 0.1$).

We also evaluated the correlations between RPI and taxa richness or diversity index (Shannon's H) of the oligochaete community via regression analysis, however, no significant relationships were found.

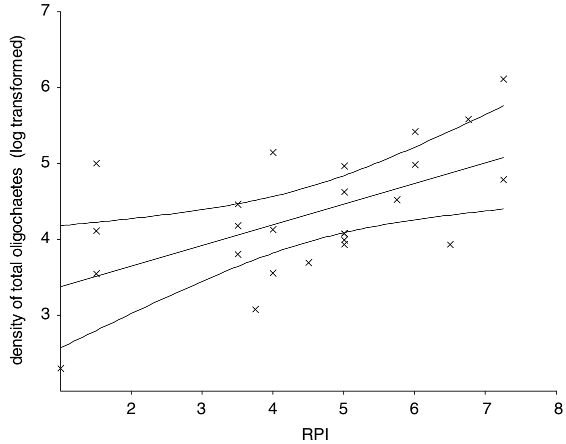

Fig 4 The linear regression of RPI and the density of total oligochaete individuals (idv/m^2, log transformed). Margin of curves indicate a 95% confidence interval ($n = 23$)

Table 3 Statistical characteristics of PCA, including the eigenvalues, percentage of variance explained, and correlations for each environmental variable for the first 3 principle components

Abbr.	Variables	PC 1	PC 2	PC 3
RPI	River Pollution Index	–0.778	0.403	–0.150
pH	pH of water	0.800	–0.379	0.054
Current	Current velocity	0.535	0.435	–0.544
Sorting	Sorting index	–0.070	0.340	–0.011
M–g	Mean grain size	0.167	0.555	0.479
TOM	Total organic matters	–0.391	0.517	0.515
VC%	% Of vegetation coverage	–0.638	–0.614	0.096
Cobbles	Big cobbles present	0.104	0.688	–0.285
Gravel	Gravel present	0.539	0.669	–0.021
Algae	Filamentous algae present	–0.041	0.272	0.762
Dis.	Distance from estuary	0.732	–0.270	0.482
Eigenvalue		2.456	2.089	1.347
% Of variance explained		27.9%	23.7%	15.3%

Species–environment relationships

The relationship between the population density of the 12 dominant species and measured environmental variables were evaluated by applying CCA. The five rare species were excluded from the analysis to avoid misrepresentation of the sampling data (Fig. 5). The scores for each species on the bi-plot of gradient ordination showed that *L. hoffmeisteri*, *Aulophorus furcatus, Pristina longiseta*, and *Allonais gwaliorensis* (located at the right side of the diagram) can tolerate more polluted habitats, while *Nais communis* (located left below) preferred habitats at the upper reaches where the RPI value is lower. Similarly, populations of *Aulodrilus pigueti*, *Branchiura sowerbyi*, *Pristinella jenkinae*, and *Stephensoniana trivandrana* preferred habitats with vegetation and fine sediments. However, populations of *Dero digitata* and *Pristina synclites* showed less correlation

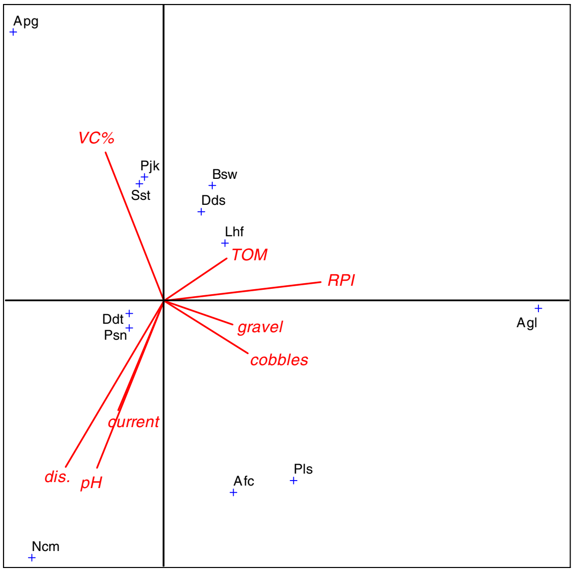

Fig 5 An ordination CCA bi-plot shows the most abundant 12 oligochaete species (crosses) and the environmental variables (vector lines) in all sites (26 samples). For species and variable abbreviations see Tables 2 and 3

with measured environmental variables as shown by their central location on the plot.

The percentage of species–environment variance explained is 26.0% for the first axis, 18.3% for the second axis, and 7.6% for the third axis (eigenvalues are 0.830, 0.584, and 0.242, respectively). The statistical significance of species–environment correlations was verified ($P < 0.1$) by using a 999-times Monte Carlo permutation test.

Discussion

Sampling technique for the oligochaete survey

Why are there so few aquatic oligochaete species recorded in macroinvertebrate survey studies in Taiwan? Not only has this field received little attention but also sampling methods may be to blame. Surber's net or kick-net with a 24-mesh (0.595 mm) is the only tool required for macroinvertebrate sampling in the official sampling protocol carried out by most researchers in Taiwan. However, the mesh is too large and some organisms, especially naidids and immature tubificids, might pass through the nets (Nalepa & Robertson, 1981). Strayer (1990) suggested that sieves, as fine as 0.05 mm may be required for work on naidids, as did Nijboer et al. (2004) who also recommended that the sieves be between 100–250 μm. The use of larger nets can likely be explained by the difficulty in sieving a sample with mud and debris through a mesh smaller than 0.1 mm. However, our experience appears that a 0.25 mm screen is acceptable and the usage of corer samplers is preferable to nets for quantitative works in muddy substratum.

Habitat variability and oligochaete community structure in Taichung Water Basin

Although the pollution level of the Dali Stream increased in winter the event did not significantly increase the average abundance of oligochaetes. The results from the MDS indicated that the oligochaete community structure did not vary greatly between summer and winter. In addition, not all the sampling sites showed an identical trend of seasonal variations statistically between summer and winter. This result may be explained by the nature of fickle habitats of the urban watercourses. The short-term complex microhabitat conditions, such as organic contamination, floods, or artificial sediment disturbance may be the key driving force in the formation of the oligochaete community composition rather than seasonal factors. Lin et al. (2005) found that the abundance of *L. hoffmeisteri* rose in winter, due to the organic precipitation accumulation in dry season. However, the observation was made from a homogenous habitat of Dali Stream at a small spatial scale. In this study, we found that the coverage of macrophytes and algae increased in winter, while the abundance of some naidids increased, with the exception of *L. hoffmeisteri* in some sites. Naidids show strong seasonal variation in its abundance with environmental changes (Juget & Lafont, 1994; Sloreid, 1994; Armendráiz, 2000). However, seasonal patterns might vary due to the local conditions. For example, Pathiratne & Weerasundara (2004) found the seasonal variation pattern of species composition in a highly polluted lake distinctly differed from less polluted reservoirs. Thus, we conclude that the variation of habitat may have a great influence on the composition of the oligochaete community structure in the Taichung Water Basin.

The habitat and ecology of oligochaetes in the Taichung Water Basin

As expected, *L. hoffmeisteri* is the most abundant species, almost distributed across all polluted sites. This species was particularly prominent in the Lyu Ditch, a foul drainage in the prosperous area of Taichung City, where its density was measured at over 1,000,000 idv./m^2. *L. hoffmeisteri* and other tubificids were however, absent from Heng Keng, a filthy creek near the piedmont, where the naidid *Aulophorus furcatus* occurred in massive numbers. Thus, *L. hoffmeisteri* is not ubiquitous in all polluted places despite its tolerance to pollution, and some naidids may respond to organic pollution by increasing in numbers, especially on the stony substrata (Mason, 1996) or some lake environments (Pathiratne & Weerasundara, 2004). Results from the CCA indicated that the naidid *Allonais gwaliorensis* also correlated with high RPI value. In fact, it was only found in the Lyu Ditch along with innumerable *L. hoffmeisteri*, indicating that it might also tolerate extremely polluted habitats. Although *Printina longiseta* and *Dero digitata* also occurred in the Lyu Ditch, their distribution was relatively sparse.

Our observations indicate that *Nais communis* may be intolerant to pollution. Results from the CCA indicated that *N. communis* preferred to inhabit the upstream reach of the stream where the current is more rapid. This result coincides with a study by Learner et al. (1978) where *N. communis* distributed longitudinally, and preferred headwaters and upper reaches. Similarly, Nijboer et al. (2004) found *N. communis* abundance corresponded with higher current velocity. However, relative to other pollution intolerant species from the genus *Nais*, *N. communis* is considered to be one of the more tolerant species (Learner et al.,1978) and has shown some preference for organic matter and detritus (Verdonschot, 1999, 2001). We found a low abundance of *N. communis* in moderately or heavy polluted areas, while it dominated at some slightly polluted and unpolluted upstream areas. We suggest that unfavorable habitat conditions and competition exclusion from other pollution tolerant oligochaetes may explain the distribution patterns of this species.

Macrophyte vegetation or algae may be an important attraction for some species. *Aulodrilus pigueti*, which constructs long tubes of mud, was primarily found in soft-bottomed habitats covered with water hyacinth (*Eichhornia crassipes*), but *Branchiura sowerbyi*, *Pristinella jenkinae*, and *Stephensoniana trivandrana* prefered to live in pools or running habitats where emergent Poaceae aquatic plants dominate the riparian vegetation. *Stylaria fossularis* was collected from an irrigation canal, and appeared to crawl on the filamentous algae or bored into decayed stems of submerged plants instead of the substratum. This habit may be common among *Stylaria* since another species of this genus, *Stylaria lacustris*, was shown to correspond with the presence of leaves via CCA (Verdonschot, 1999, 2001), and commonly occurs among water plants (Timm & Veldhuijzen van Zanten, 2002).

Marionina sp. of Enchytraeidae, was found only in the midstream of the Han Stream. This species may be sub-terrestrial and prefers to live in the deeper stratum or near terrestrial zones. The presence of this species at only this site can likely be explained by the dredging work that was taking place in the hyporheic zone of this sampling site during the sampling period.

Applications of pollution assessments and biotic indices

The taxa richness or diversity index of benthic marcoinvertebrates could be a criterion for assessing wastewater pollution (Wilhm & Dorris, 1968). However, in accordance with Hsieh et al. (1998), since we found no significant correlation between RPI and taxa numbers or diversity index of oligochaetes in this study, it may not be suitable to for use in assessing the oligochaete community. The proportion of tubificids to total oligochaete numbers seems to be a practical index in this study, yet it was only representative of the dominant *L. hoffmeistri* since we found only three species of tubificids. The oligochaete index IOBS (Lafont, 1989), uses the proportion of species richness and the relative abundance of tubificids simultaneously for environmental impact assessments of heavy metals (Rosso et al., 1994) and toxic substances, such as PCBs or PAHs (Lafont et al., 1996; Prygiel et al., 2000). However, the application of the index was limited on the environments with fine sediment and may not be applicable for our study due to the nonexistence of any tubificids in some sites with bouldery riverbed.

Our results implied that biotic indices should not be limited to representation by tubificids only but should also include pollution-tolerant naidids.

Absent significant correlations between oligochaete abundance and a single environmental parameter are likely, because populations are simultaneously affected by more than one variable. For example, Yu et al. (1995) reported that the abundance of "*Tubifex* sp." had a significantly positive correlation with BOD_5 and NH_4^+–N, while Sang (1987) did not find a significant relationship between total oligochaete number and any of the six chemical factors measured (COD, NH_4^+–N, NO_3^-–N, Hg, Cr, and Pb). Our results, however, present a clear relationship between organic pollution and the density of oligochaetes since we used a synthetic pollution index, RPI, which includes several key factors.

Our study suggests that oligochaete density may still be a reference index for domestic-sourced organic pollution in the Taichung Water Basin. However, the density thresholds in this study may not be suitable for other cases since it is difficult to ensure the standards of different pollution states and because the impacts of organic pollutants on oligochaete community structure are not fully demonstrated or understood (Sang & Erséus, 1985). Although oligochaetes generally occur in polluted places they may be absent or minimal due to unfavorable oxygen regimes and sediments (Slepukhina, 1984), or the excessive presence of chemical pollutants such as PAHs, PCBs, and heavy metals (Prygiel et al., 2000). In addition, climactic or tropic conditions may also be limiting factors for the oligochaete population density in different regions. For example, oligochaete density has been reported over 1,320,000 idv./m^2 (only *L. hoffmeisteri*) in the Keelung River, Northern Taiwan (Hsieh et al., 1998), at 700,000 idv./m^2 in the lower Pearl River, southern China (Sang & Erséus, 1985), but lower than 10,000 idv./m^2 in the urban watercourses of Ussurisk, Eastern Russia (Timm, 1997).

Some researchers have attempted to determine the factors that influence species composition via the multivariate ordination technique. Schenková et al. (2001) described the relationship between oligochaete species and habitat variables by applying CCA. However, results indicated that some factors like hardness, NO_3^-–N, Ca^{2+}, Mg^{2+}, and altitude were significant while intuitional factors such as BOD, NH_4^+–N, or TOC were not. Nijboer et al. (2004) evaluated more than 20 variables, however, some key variables, such as organic pollution, were excluded from the analyses due to missing data. Potentially these studies were designed under a large-scale viewpoint that emphasized habitat landscape characteristics rather than microhabitat effects.

Since the goal of our study is a pollution assessment, we focused only on the magnitude of organic pollution (RPI), substrate types, and some specific habitat characteristics. We used the ordination technique as a means of understanding environmental preferences of each species. However, since ordination gives only correlations between environmental variables and species distribution and does not reveal causal relationships (Nijboer et al., 2004), it cannot be used as a tool for determining the actual factors within dozens of variables that may affect species distribution.

The pollution levels of urban watercourses and rivers vary and the marcoinvertebrate community is often assembled monotonously with the presence of restricted groups such as Oligochaeta, Hirudinea, Chironomidae (Diptera), Syrphidae (Diptera), and Physidae (Mollusca). Biotic indices based on aquatic insect families may not be sensitive enough to observe regional variances such as the progression of sewage reduction. Our results provide the potential for using oligochaetes at the species level as indicators. For example, the species scores projected along CCA axes represent their tolerances to environmental variables (Martínez-Ansemil & Collado, 1996). Therefore, according to our results, the first axis reflects adaptation with regard to the gradient of organic pollution, and the scores could provide reliable criteria for formulating a relative tolerance value against another reference taxon such as chironomids. This is a practical way to establish a regional supplement of biotic indices for pollution assessment applications.

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