Evaluation of alternative macroinvertebrate sampling techniques for use in a new tropical freshwater bioassessment scheme

Uma avaliação de técnicas alternativas de amostragem de macroinvertebrados para uso na bioavaliação de sistemas aquáticos tropicais

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Abstract: Aim: The study aimed to determine the effectiveness of benthic macroinvertebrate dredge net sampling procedures as an alternative method to kick net sampling in tropical freshwater systems, specifically as an evaluation of sampling methods used in the Zambian Invertebrate Scoring System (ZISS) river bioassessment scheme. Tropical freshwater ecosystems are sometimes dangerous or inaccessible to sampling teams using traditional kick-sampling methods, so identifying an alternative procedure that produces similar results is necessary in order to collect data from a wide variety of habitats. **Methods:** Both kick and dredge nets were used to collect macroinvertebrate samples at 16 riverine sites in Zambia, ranging from backwaters and floodplain lagoons to fast flowing streams and rivers. The data were used to calculate ZISS, diversity (S: number of taxa present), and Average Score Per Taxon (ASPT) scores per site, using the two sampling methods to compare their sampling effectiveness. Environmental parameters, namely pH, conductivity, underwater photosynthetically active radiation (PAR), temperature, alkalinity, flow, and altitude, were also recorded and used in statistical analysis. Invertebrate communities present at the sample sites were determined using multivariate procedures. **Results:** Analysis of the invertebrate community and environmental data suggested that the testing exercise was undertaken in four distinct macroinvertebrate community types, supporting at least two quite different macroinvertebrate assemblages, and showing significant differences in habitat conditions. Significant correlations were found for all three bioassessment score variables between results acquired using the two methods, with dredge-sampling normally producing lower scores than did the kick net procedures. Linear regression models were produced in order to correct each biological variable score collected by a dredge net to a score similar to that of one collected by kick net sampling. **Conclusions:** The use of a dredge net in macroinvertebrate bioassessment schemes is an effective, alternative method in certain environments when site conditions prohibit the use of the preferred kick net sampling method. The results of this study can be used to aid in the development of other tropical freshwater bioassessment schemes around the world, including Brazil.

Keywords: limnology; Zambia; ZISS: Zambian Invertebrate Scoring System; dredge net; kick net; benthic invertebrates.

Resumo: Objetivo: Este estudo pretendeu determinar a eficácia dos procedimentos de amostragem de macroinvertebrados bentônicos em sistemas aquáticos tropicais, através de rede de dragagem ("dredge net") em alternativa ao método de rede de pontapé ("kick net"), particularmente na avaliação dos métodos de amostragem utilizados no Sistema de Classificação de Invertebrados de Zâmbia (ZISS). Os ecossistemas tropicais de água doce são algumas vezes inacessíveis ou perigosos de serem amostrados com o método tradicional de rede de pontapé, assim é necessário encontrar um procedimento alternativo que permita a obtenção de resultados semelhantes para a coleta de dados em uma grande variedade de habitats. **Métodos:** Ambos os métodos de amostragem (rede de dragagem e rede de pontapé) foram usados para coletar amostras de macroinvertebrados em 16 locais em Zâmbia, abrangendo desde remansos e lagoas de inundação, até riachos e rios de grande velocidade de corrente. Os dados foram usados para o cálculo de ZISS, diversidade (S: número de táxons) e escores por local (Average Score Per Taxon: ASPT), usando os dois métodos de amostragem para comparar a sua eficiência de amostragem. As variáveis pH, condutividade, radiação fotossinteticamente ativa (RFA), temperatura, alcalinidade, velocidade de corrente e altitude também foram obtidas e usadas nas análises estatísticas.

As comunidades de invertebrados presentes nos locais de coleta foram determinadas através de procedimentos multivariados. **Resultados:** A análise da comunidade de invertebrados e dos dados ambientais sugerem que o teste foi realizado em quatro tipos distintos de comunidades de invertebrados, com pelo menos dois agrupamentos muito diferentes entre si e mostrando diferenças significativas nas condições dos habitats. Correlações significativas foram encontradas para todos os três escores das variáveis de bioavaliação entre os resultados obtidos usando os dois métodos, com a rede de dragagem produzindo normalmente menores escores do que aqueles com o procedimento com a rede de pontapé. Modelos de regressão linear foram produzidos para corrigir o escore de cada variável biológica coletada com a rede de dragagem com o escore similar daquele coletado com a rede de pontapé. **Conclusões:** O uso da rede de dragagem na bioavaliação com macroinvertebrados é um método alternativo efetivo em certos ambientes nos quais as condições proíbem o uso do método preferencial de rede de pontapé. Os resultados deste estudo podem ser usados como auxílio no desenvolvimento da bioavaliação em outros ambientes de água doce tropicais do mundo, incluindo o Brasil.

Palavras-chave: limnologia; Zâmbia; ZISS: Sistema de Classificação de Invertebrados da Zâmbia; rede de dragagem; rede de pontapé; invertebrados bentônicos.

1. Introduction

The use of bioassessment methods to determine water quality in freshwater systems has become common practice in many countries around the world, including the United States, South Africa, Australia, and all countries of the European Union (e.g. Wright et al., 1998; Smith et al., 1999; Barbour et al., 1999; Swedish Environmental Protection Agency, 2000; Dickens & Graham, 2002; Murphy et al., 2002; Ollis et al., 2006; Dallas et al., 2010; Friberg et al., 2010; Turley et al., 2014). These simple biologically-based assessment protocols are often less expensive and produce faster results than traditional physico-chemical testing, and use the presence of various different aquatic indicator taxa to give a quantitative measure of the health of the freshwater ecosystem (Lowe et al., 2012a; Turley et al., 2014). Although there are as yet no internationally-agreed sampling procedures for freshwater bioassessment, trends can be seen between aquatic communities that demonstrate enough similarities to permit basic comparisons to be drawn between ecoregions (Abell et al., 2008), and sampling protocols for new bioassessment schemes to be adapted from previous ones (e.g. Murphy et al., 2002; Lowe et al., 2012a; Buss et al., 2015).

Macroinvertebrates are a commonly used indicator group for this purpose, as are fish, benthic diatoms, and macrophyte communities (e.g. Barbour et al., 1999), because the presence or absence of various taxa (usually at family level) in a freshwater ecosystem is strongly correlated with environmental parameters, such as temperature, toxic pollutants, and suspended sediment (Ogbeibu

& Oribhabor, 2002; Durance & Ormerod, 2009; Clapcott et al., 2012; Xu et al., 2014).

A number of countries in tropical Africa, Asia and South America, including Brazil, have been developing macroinvertebrate-based bioassessment methods for their own aquatic ecosystems (e.g. Palmer et al., 1996; Junqueira & Campos, 1998; Junqueira et al., 2000; Palmer & Taylor, 2004; Silveira et al., 2005; Buss & Borges, 2008; Monteiro et al., 2008; Roque et al., 2008; Dallas, 2009; Hartmann et al., 2010; Lowe et al., 2012a; Melo et al., 2015). The Zambian Invertebrate Scoring System (ZISS) is one such example. This scheme has been recently developed to help determine the quality of tropical freshwater systems by sampling macroinvertebrate communities in Zambian rivers (Lowe et al., 2012a). Because there had been very few preceding studies of the macroinvertebrate populations and water quality of Zambia's rivers, this scheme effectively commenced the process of biomonitoring the health of freshwater systems in this tropical country (Lowe et al., 2012a).

The ZISS scheme uses a kick net sampling procedure as its standard approach for sampling benthic macroinvertebrate communities (Lowe et al., 2012a, b). It is not, however, always possible to use this method in Zambian rivers, particularly because of the potential threat posed by dangerous aquatic wildlife (e.g. hippopotamus and crocodiles), which may make entering a water body on foot too dangerous. Because of this problem, it is important to have an alternative method that produces comparable results to the kick net approach, in order to obtain appropriate bioassessment data from sites in Zambia, and in

other tropical freshwater systems with similar safety issues.

The purpose of this study was to determine if a dredge net, which can safely be used to collect samples from the bank of a water body, or from a boat, can produce similar results to the data on Zambian benthic invertebrate communities that are obtained by kick net sampling. Any quantitative and significant relationship found between the data collected by the kick net and the dredge net approaches could be used to correct the results from dredge net sampling data to results similar to those collected by kick net sampling.

2. Material and Methods

2.1. Study area

Zambia is a landlocked, southern African country centred at 15°00' S and 30°00' E. Sampling for this study was undertaken in the northern half of the country, located in the Kasanka National Park, and Bangweulu Wetlands (located in freshwater ecoregion Bangweulu-Mweru: Abell et al., 2008; WWF, 2013); and in the South

Luangwa National Park (freshwater ecoregion: Middle Zambezi-Luangwa), and included riverine floodplain aquatic systems such as backwaters and lagoons, as well as small to medium-sized river channels. In total, 25 sites (Figure 1, Table 1) were sampled in July 2013, during the southern African dry season, resulting in low water levels and no rainfall being encountered during the sampling period. The geo-coordinates and altitude of each site were recorded using a handheld Garmin Etrex GPS unit.

2.2. Field sampling

Sample collection by kick net sampling (mesh size = 1 mm) followed the protocol outlined by the Zambian Invertebrate Scoring System (Lowe et al., 2012b), with minor adjustments to the time-period spent sampling due to local conditions at individual sites. Up to three biotopes (as present at each site, namely sand gravel, mud; rock; aquatic vegetation) were sampled and the results combined to characterize the site. At all sites a dredge net (mesh size = 1 mm), attached to a 5 m cord, was also used to sample invertebrates from each biotope.
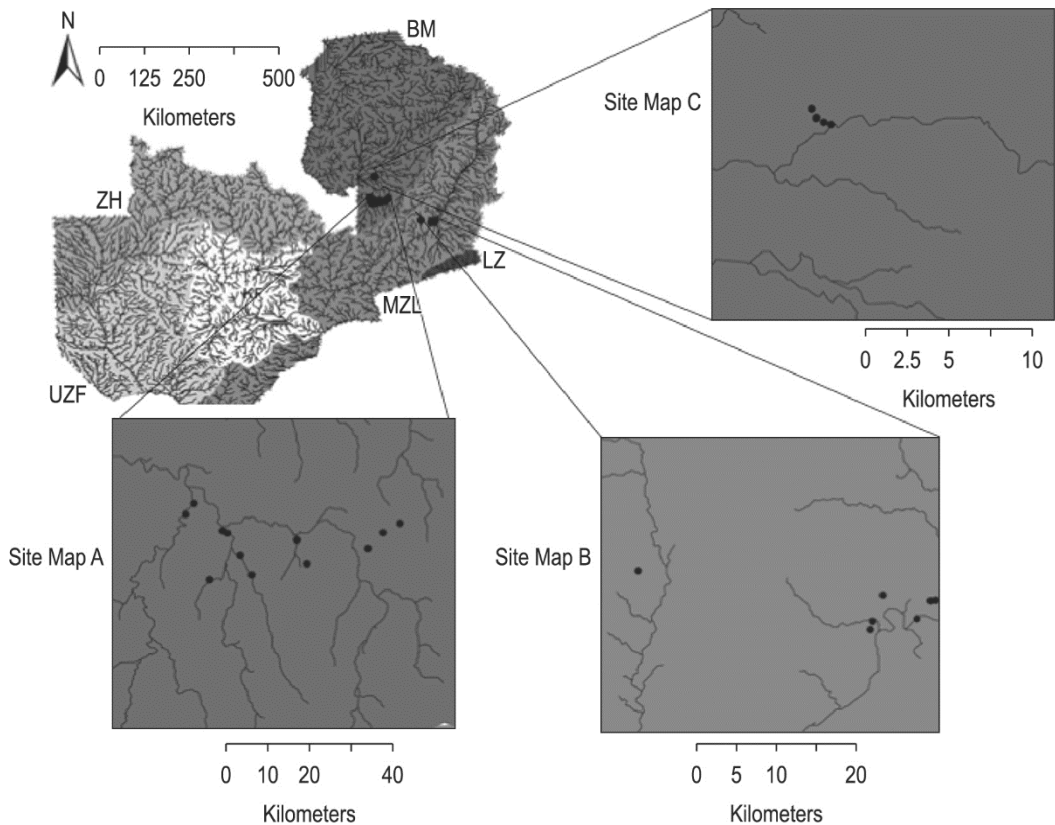
Figure 1. Map of Zambia with sampling sites shown in greater detail in additional sub site maps. Site Map A shows sites sampled in Kasanka National Park. Site Map B shows sites sampled in South Luangwa National Park. Site Map C shows sites sampled in the Bangweulu Wetlands.

Table 1. Coordinates for sites sampled in Zambia.

Site Number	Site Name	Lat (S)	Long (E)
1	Njelele	12.60864	30.39989
2	Mulaushi	12.55637	30.37608
3	Fibwe	12.59168	30.25193
4	Mulembo	12.53797	30.56644
5	Pontoon	12.57262	30.53353
6	Kabombe	12.64557	30.18482
7	Luwombwa	12.50248	30.13113
8	Luwombwa Backwater	12.47837	30.14912
9	Musola	12.63367	30.27768
10	Shoebill A	11.95111	30.23965
11	Shoebill B	11.95321	30.24393
12	Shoebill C	11.95445	30.24785
13	Shoebill D	11.95047	30.23976
14	Shoebill E	11.94584	30.2372
15	Waka Waka	12.51621	30.60274
16	Kasanka River	12.5381	30.21224
17	Kasanka Backwater	12.54324	30.22299
18	Wakumba	13.10507	31.72647
19	Wakumba II	13.11465	31.72385
20	No Name (20)	13.07476	31.73746
21	Luwangwamafwa	13.06166	31.81711
22	Chipela Lagoon	13.052	31.45268
23	Luwangwa River (Main)	13.10128	31.77786
24	Mushroom Lagoon	13.08023	31.79352
25	No Name (25)	13.07927	31.79935

All collected macroinvertebrates were identified (usually to family level: see Table 3) on site, using a hand lens and a photographic identification manual developed specifically for ZISS, which lists all commonly found invertebrate families in Zambian rivers (Lowe, 2012). Subsequent confirmation of identifications was made using a portable microscope. Macroinvertebrate samples were stored in 70% ethanol to preserve them for future study.

The ZISS index, diversity (S: number of taxa present), and Average Score Per Taxon (ASPT) scores were calculated for each site, and individual scores were also calculated for each sampling method used at the sites.

Environmental parameters measured at the sampling sites were pH; conductivity; underwater photosynthetically active radiation (PAR; at two points in the water column: just below surface and at standard depth of 0.22 m unless the water was too shallow, in which case a smaller separation depth was used for the second reading),with PAR data subsequently used to calculate underwater light attenuation coefficient (k m^{-1}); temperature; visually-assessed disturbance class (on a semi-quantitative scale of 1 = no disturbance due to trampling by animals, to 4 = substantial disturbance: major trampling damage); and visually-assessed flow class (class 1= static; 2 = slow flow: "pool"; 3 = moderate flow: "glide"; 4 = fast

Table 2. Environmental and biological parameters: range of data for all 25 sites, and mean ± standard error (SE) for each of four TWINSPAN sample groups compared by ANOVA.

		TWINSPAN Sample Groups				
		I	II	III	IV	P$_{ANOVA}$
Variable	Range	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	
pH	6.00-9.36	7.67 ± 0.14[a]	7.25 ± 0.12[a]	7.89 ± 0.27[a]	6.55 ± 0.27[b]	<0.005
Temperature (°C)	12.00-29.90	20.5 ± 1.79	20.66 ± 2.22	19.7 ± 8.68	22.05 ± 1.87	>0.05 NS
Flow	1.00-4.00	1.50 ± 0.50[a]	1.29 ± 0.18[a]	3.00 ± 0.31[b]	1.50 ±0.29[a]	<0.005
Disturbance	1.00-4.00	2.00 ± 0.37[a]	2.14 ± 0.26[a]	1.14 ± 0.14[b]	1.50 ± 0.29[a]	<0.05
Conductivity (µS cm^{-1})	6.00-625.00	217.30 ± 99.43	84.00 ±23.62	53.00 ± 17.69	30.50 ± 12.20	>0.05 NS
k (m^{-1})	0.70-26.86	12.16 ± 5.00	11.45 ± 4.58	4.62 ± 2.41	11.32 ± 4.95	>0.05 NS
Alkalinity (microEq L-1)	78.22-4386.29	1845.00 ± 676.60	1055.00 ± 329.55	844.00 ±286.47	552.00 ± 262.00	>0.05 NS
Altitude (m)	511.00-1273.00	858.00±154.43	886.90 ± 130.99	1085.10± 95.77	1168.00 ± 8.60	>0.05 NS
Kick $_S$	3.000-16.00	9.00 ± 1.29	9.00 ± 0.82	10.57 ± 1.48	5.25 ± 0.48	>0.05 NS
Dredge $_S$	0.00-12.00	6.33 ± 1.41	7.29 ± 1.30	6.28 ± 1.60	3.75 ± 0.85	>0.05 NS
Kick $_{ASPT}$	3.00-6.82	4.24 ± 0.29	4.58 ± 0.43	4.83 ± 0.39	3.56 ± 0.26	>0.05 NS
Dredge $_{ASPT}$	0.00-5.25	3.89 ± 0.49	4.04 ± 0.19	3.68 ± 0.64	3.83 ± 0.15	>0.05 NS
Kick $_{ZISS}$	10.00-79.00	38.83 ± 6.85[a]	40.71 ± 3.95[a]	53.00 ± 8.66[a]	18.75 ± 2.46[b]	<0.05
Dredge $_{ZISS}$	0.00-52.00	26.50 ± 6.34	30.57 ± 6.19	27.57 ± 7.30	14.50 ± 3.71	>0.05 NS

For variables with significant ANOVA outcomes only (P<0.05) mean values with a superscript letter in common do not significantly differ between sample groups (Tukey's mean separation test). No statistical test was applied to geo-coordinates data.

flow: "riffle" or white water showing). Field meters used were a Handylab pH/temperature LF12 meter, HI98311 conductivity meter, and a SKYE SKP210 underwater PAR sensor. A water sample was taken at each site for subsequent alkalinity analysis (Neal, 2001).

2.3. Data analysis

Ryan-Joiner testing was used to determine the normality of the response data for each variable subject to statistical testing, and a natural log transformation was used to normalize datasets if needed. In order to determine the range of benthic macroinvertebrate communities present at the test sites, and their relationship with ambient environmental conditions, the macroinvertebrate and environmental data were analyzed using the multivariate ordination method Canonical Correspondence Analysis, (CCA; Version 4.5 CANOCO for Windows), to analyze both the samples *versus* taxa datasets and the samples *versus* environmental variables dataset (ter Braak & Smilaŭer, 1998). The significance of ordination outcomes was determined by Monte Carlo testing. In addition, Two-Way Indicator Species Analysis (TWINSPAN) was used to classify taxa datasets into internally similar groups (Hill, 1979). Comparisons were made between mean values of 10 variables (pH, conductivity, flow class, turbidity (k m⁻¹), disturbance class, alkalinity, altitude, diversity (S), ZISS, and ASPT) for sample groups produced by TWINSPAN using one-way analysis of variance (ANOVA: with Tukey's multiple-comparison test for significant outcomes), using Minitab, version 15.1.30.0. Data presented (see Table 2) were back-transformed (for variables where significance testing had been undertaken using log values) for ease of comparison.

3. Results

In total, 42 different benthic macroinvertebrate taxa from 13 groups/orders were collected at the sample sites (Table 3). TWINSPAN classification identified four main sample groups (I-IV) and two main taxa assemblages (A and B). Assemblage A (*n* = 24 taxa) comprised taxa such as Corixidae and Culicidae which both have high abundances in sample groups I and II, but were almost completely absent from sample groups III and IV. Assemblage B (*n* = 20 taxa) was made up of taxa such as Atyidae and Leptoceridae, which were commonly found in sample groups III and IV, but are absent from groups I and II. These differing assemblages suggest

that there was a substantial difference between the sites where Assemblage A taxa were more commonly found, and the sites where Assemblage B taxa were predominant.

The four sample groups differed significantly in terms of a number of the biological and

Table 3. Macroinvertebrate families and orders recorded from sample sites. Following ZISS protocol, sampled taxa are identified mostly to family level (Lowe et al., 2012a). However, there are some exceptions, including Annelida, Oligochaeta, and Turbellaria which are only required to be identified to subphylum or class and are listed below in bold.

Group/Order	Family
Annelida	
Coleoptera	Noteridae/Dytiscidae
	Limnichidae
	Hydrophilidae
	Gyrinidae
	Hapliplidae
Decapoda	Atyidae
Diptera	Chironomidae
	Culicidae
	Simuliidae
	Dixidae
Ephemeroptera	Baetidae
	Prosopistomatidae
	Tricorythidae
	Caenidae
Gastropoda	Lymnaeidae
	Planorbinae
	Bithyniidae
	Ancylidae
	Ampularidae
	Bulininae
	Hydrobiidae
	Thiaridae
Hemiptera	Gerridae
	Nepidae
	Naucoridae
	Veliidae
	Corixidae
	Notonectidae
Hirudinae	
Lepidoptera	Crambidae
Odonata	Libellulidae
	Coenagrionidae
	Calopterygidae
	Aeshnidae
Oligochaeta	
Pelecypoda	Sphaeriidae
Plecoptera	Perlidae
Potamonautidae	
Trichoptera	Leptoceridae
	Hydropsychidae
	Polycentropodidae
Turbellaria	

environmental variables measured (Table 2). Indicator taxa distinguishing them are listed below (note that under the ZISS system, the presence of >1 species within certain families differentiates them, and provides differing ZISS scores; e.g. Baetidae: 1 species = ZISS score 4; 2 species = ZISS score 6; >2 species = ZISS score 12 (Lowe et al., 2012c)). Group I was indicated by Gyrinidae, Culicidae, Gerridae, and Ampularidae; Group II: Baetidae (1 species) and Oligochaeta; Group III:- Coenagrionidae, Baetidae (2 species), Libellulidae, Baetidae (1 species), Atyidae, and Leptoceridae; and Group IV: Hydrophilidae.

Significant differences in environmental and biological variables between sample groups, (detailed in Table 2) can be summarised as follows: Groups I and II: high disturbance and conductivity, low altitude and flow, fewer pollution-sensitive taxa (such as Oligochaeta and Corixidae); Groups III and IV: low disturbance and conductivity, high altitude and flow, presence of more sensitive taxa (such as Atyidae and Coenagrionidae).

The ordination analysis (Figure 2) indicated the importance of flow, disturbance, altitude, and conductivity as major predictors of macroinvertebrate community. Less important environmental drivers include water clarity, pH, and alkalinity. When TWINSPAN groups were overlaid onto the ordination site-plot, the different site-groups were shown to be associated with varying environmental parameters
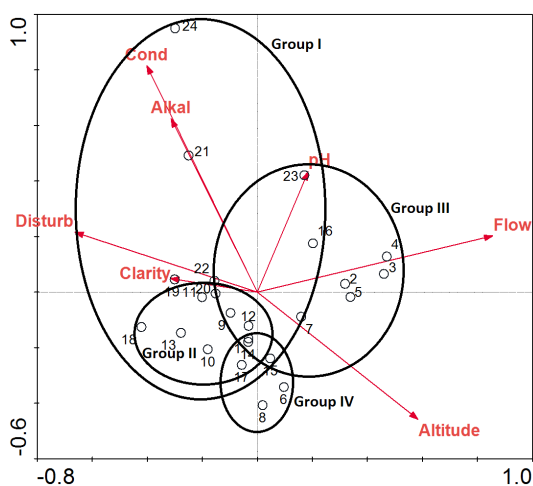
Figure 2. CCA site ordination plot with TWINSPAN sample-groups overlain, showing relation between environmental variables and 4 site-groups (I: characterised by abundant Gerridae, Gyrinidae, Culicoidae, and Ampularidae; II: Baetidae (single species), Oligochaetae; III: Coenagrionidae, Libellulidae, Baetidae (>1 species), Atyidae and Leptoceridae; IV: abundant Hydrophilidae).

and influenced slightly by their geographical location. Sites sampled in South Luangwa and the Bangweulu Wetlands were found primarily in Groups I and II, while Groups III and IV were mostly comprised of sites located in Kasanka National Park.

In order to assess the usefulness of the dredge-sampling approach, compared with the standard kick-sample protocol, across the range of invertebrate communities and environmental conditions present at the survey sites, a series of comparisons was made, as detailed below.

The highest ZISS score, at any site, recorded by kick-sampling was 79 (indicating very good river ecosystem health), whilst the lowest (10) indicated poor water conditions at that particular site. The comparison of the three metrics ZISS, diversity (S) and ASPT scores, using data collected by each sampling method, showed a difference between the values produced by kick net sampling and the values produced by dredge net sampling, with dredge-sampling usually underestimating the values produced by kick-sampling. Whilst all kick net samples yielded invertebrate specimens, some dredge net samples failed to collect invertebrates at all: for example when bedrock was the substratum, resulting in scores of zero for ZISS, S, and ASPT. A significant statistical correlation between dredge score and maximum score was found between the calculated values of each quantitative biological variable, which allowed linear regression models to be created that could be used to correct scores derived from the less-efficient dredge-sampling method.

A significant positive correlation was found between the maximum ZISS score recorded at each site and the ZISS score recorded from samples collected by a dredge net ($r = 0.532$, $p = 0.034$, r^2 *(adj)* = 23.3%). A linear regression analysis produced the equation:

$$\text{Kick}_{ZISS} = 22.6 + 0.633\ \text{Dredge}_{ZISS} \tag{1}$$

which can be used to correct ZISS scores collected by dredge-sampling to a score similar to that of one collected by kick net sampling.

There was a significant positive correlation between macroinvertebrate diversity (S) collected by dredge net and kick net sampling ($r = 0.547$, $p = 0.028$, r^2 *(adj)* = 24.9%). A linear regression analysis produced the equation:

$$\text{Kick}_{S} = 4.71 + 0.608\ \text{Dredge}_{S} \tag{2}$$

which can be used to correct diversity scores collected by dredge-sampling to a score similar to that of one collected by kick net sampling.

There was a significant negative correlation between the ASPT scores collected by dredge-sampling and kick net sampling ($r = -0.525$, $p = 0.037$, r^2 *(adj)* = 22.4%). A linear regression analysis of ASPT scores collected by kick net and by dredge net produced the equation:

$$\text{Kick}_{\text{ASPT}} = -5.98 - 0.419 \text{ Dredge}_{\text{ASPT}} \qquad (3)$$

which can be used to correct scores collected by dredge net sampling to the standard kick-net based score utilised in ZISS protocol for assessing river water quality.

4. Discussion

Since kick net sampling is considered to be a highly-effective method of collecting an accurate representation of benthic macroinvertebrate communities, it continues to be the standard choice of sampling protocol for use in river bioassessment procedures utilising benthic invertebrates (Buss & Borges, 2008; Brua et al., 2011; Buss et al., 2015). Dredge-sampling is less efficient because it produces less disturbance of the invertebrate habitat during the sampling operation than does kick-sampling, and hence tends to dislodge and collect a smaller proportion of the taxa present. However, in conditions where environmental conditions (such as the presence of dangerous wildlife, inaccessibility due to water depth or fast flow) prevent the use of procedures which require sampling personnel to enter the water, an alternative method of sampling must be identified, which produces data that can be converted back to results that would be obtained by standard kick-sampling. So long as the two methods produce comparable values for benthic metrics and community composition, then samples collected by either method should be able to be combined for bioassessment purposes (Brua et al., 2011). Here we show that this is possible for bank- or boat-based dredge-sampling, by utilising simple linear regression models (Equations 1-3) to correct and standardise the results obtained by the dredge-sampling procedure so that the data can be used in the ZISS assessment protocol. This allows a less efficient (but safer) sampling methodology to be used where a more efficient procedure might not be an option.

This study provides an initial indication of the potential value of dredge-sampling for bioassessment using benthic macroinvertebrate populations in tropical rivers and associated riverine floodplain water bodies, and shows that the results obtained can be relied upon, after correction for the known inefficiency of the technique, using the models presented here (Equations 1-3) to collect samples that reasonably and accurately represent the macroinvertebrate communities present at a selected site. At sites where both methods were used, the dredge usually collected a lower diversity of taxa and gave a lower total ZISS score, but by using linear regression equations, the ZISS, diversity, and ASPT scores collected by dredge-sampling can be corrected to estimate results similar to those that would have been collected by a kick net. However, because the correlations between the variable scores of both methods only explained a moderate proportion of the variability, each with an estimated r-value of 0.500-0.600, it is clear that more data needs to be collected, across a wider range of appropriate habitats, to permit the development of more precise correction factors for the dredge method. Future dredge protocol development is also needed in order to ensure that the sampling effort of using a dredge-sampler is the same as the effort of using a kick net. The dredge protocols used in this study, however, did seem to produce relatively similar results to that of the kick net at each site, so they can be considered a good base to build upon.

5. Conclusions

This study indicated that results found by two different macroinvertebrate sampling methods are statistically significantly-related, across a range of sites located in different ecoregions in Africa, and supporting differing habitat conditions and invertebrate communities. This knowledge is beneficial in the development of biomonitoring systems that are required to sample a large range of different aquatic habitats in tropical rivers with varying restrictions on sampling methods. Improved availability of alternative approaches for sampling in river bioassessment schemes can contribute to improved understanding of the health of tropical aquatic systems, and the challenges that are faced in maintaining such water resources in good quality.

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