The relationship between concurrently measured SASS (South African Scoring System) and turbidity data archived in the South African River Health Programme's Rivers Database

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ABSTRACT

The need for monitoring the biological impacts of instream sediments has long been recognised, yet robust and scientifically defensible tools for doing so are still in the early stages of development because of the difficulties experienced by researchers in characterising the complicated mechanisms of biological effect elicited by sediment particles. Biological monitoring is one such tool, and this paper reports on the initial stages of a study to determine the most applicable approach for measuring the effects of instream sediments on aquatic macroinvertebrates in the South African context. In this first instance, the suitability of the rapid macroinvertebrate biomonitoring tool (the South African Scoring System) was investigated by determining the extent of the correlation between concurrently measured SASS metrics and turbidity data collected for the South African River Health Programme. All three SASS metrics – SASS score, number of taxa (NOT), and average score per taxon (ASPT) – were found to be significantly negatively correlated with turbidity, although variation in the data was high. Turbidity was found to be the major driver of change in ASPT. In contrast, electrical conductivity was the major driver of SASS scores and NOT, with turbidity a close second. When combined, electrical conductivity and turbidity accounted for 80% (SASS score) and 75% (NOT) of the variation in the regression model. Consequently, SASS metrics are a crude, but reliable, indicator of the negative biological implications of excessive instream sedimentation as measured by turbidity. A number of other potential biomonitoring approaches for detecting the impacts of fine sediment exposure are identified for further investigation: spatial analyses of macroinvertebrate assemblages; and the use of structural and functional metrics.

Keywords: aquatic macroinvertebrates, suspended sediment, biomonitoring

INTRODUCTION

While sediment is a fundamental and necessary part of aquatic ecosystems and their functioning, elevated sediment concentrations influence aquatic biota through both direct and indirect means, producing complex interactions affecting individuals, populations and whole communities (Dunlop et al., 2008). Direct effects on macroinvertebrates from suspended sediment include clogging and/or abrasion of gills (leading to reduced organism condition) and filter-feeding organs (leading to reduced feeding efficiency) (Bilotta and Brazier, 2008; Jones et al., 2011), while settled sediment particles can bury benthic macroinvertebrates and smother eggs causing mortality (Jones et al., 2012). Indirectly, suspended sediments can increase turbidity and change predator–prey relationships due to visual impairment (resulting in reduced growth or condition) (Jones et al., 2012), while settled sediments can alter habitat (Wood and Armitage, 1997) and food availability (Peeters et al., 2006) leading to a change in community composition (Bo et al., 2007).

The need to manage instream sediment concentrations is thus evident. One of the most effective tools for managing environmental water quality is field biomonitoring. Currently, however, there is no biomonitoring method capable of assessing the direct or indirect effects of elevated instream sediment levels. Gaining an understanding of the most appropriate (in terms of sensitivity and practicality) biomonitoring approach for measuring biological effects of instream sediment is warranted, and is the subject of this paper.

The South African Scoring System (SASS) (Dickens and Graham, 2002) is a rapid macroinvertebrate biomonitoring approach originally developed to monitor organic pollution. However, it has subsequently been widely applied, successfully, to measure the biological effects of other pollutants (Ollis et al., 2006). Consequently, it may also have the potential to provide an indication of instream sediment impacts. The advantage of the SASS approach is that it is widely used throughout South Africa, is easy, quick and thus inexpensive to apply. However, the ability of the SASS approach to measure the biological effects of instream sediment exposure is unknown, as the sensitivity ratings used to calculate the SASS metrics were developed for organic pollution stress. In SASS, aquatic macroinvertebrate taxa have been allocated a sensitivity rating between 1 (tolerant of organic pollution stress) and 15 (intolerant). After sampling of the three main habitat types available at a site (vegetation; stones; and gravel/sand/mud), the taxa present are identified and metrics determined. The SASS metrics comprise the SASS score (the total of the sensitivity ratings of those taxa sampled at the site) the number of taxa (NOT) and the average score per taxon (ASPT – which is the SASS score divided by the NOT). In addition to investigating the potential for SASS to reflect the biological effects of instream sediment, other potential sediment-associated biomonitoring approaches described in the literature are discussed.

The Rivers Database is a repository of site-specific biological (macroinvertebrate) and water physicochemical data

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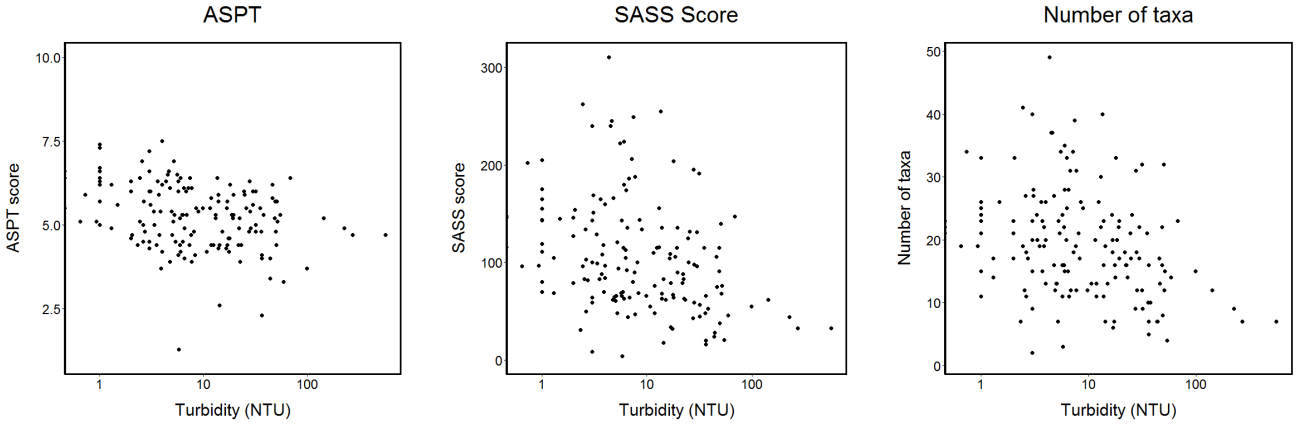

Figure 1
Scatterplots of the SASS metrics ASPT, SASS Score and Number of Taxa in relation to turbidity

collected through the activities of the River Health Programme by members of the scientific community undertaking independent research in South Africa. The macroinvertebrate data is collected using the SASS methodology (Dickens and Graham, 2002), and available together with any concurrently recorded water physicochemical data. One of the water quality variables measured by SASS practitioners, albeit infrequently, is turbidity. Turbidity measurements can, however, be affected by dissolved minerals and humic substances in the water (Bilotta and Brazier, 2008). In addition, turbidity measures may not adequately reflect the biological implications that sediment characteristics such as particle size (Jones et al., 2012), shape and angularity (Bilotta and Brazier, 2008; Collins et al., 2011) can have for an organism. However, the difficultly of measuring total suspended solids (TSS) means that there were very few concurrently measured SASS and TSS data in the Rivers Database, necessitating the reliance on the turbidity data.

Consequently, the purpose of this study is to investigate the suitability of a rapid macroinvertebrate biomonitoring tool (SASS) as a method of indicating the biological implications of instream sediment exposure. The study approach is to determine the extent of the correlation between concurrently measured SASS metrics and turbidity data, and then to discuss these results together with other potential sediment-associated biomonitoring approaches described in the literature.

METHODS

Data used in the analysis were obtained from the Rivers Database on 9 January 2012. One hundred and fifty seven (157) entries of concurrently measured SASS and turbidity data were retrieved from sites in rivers in the following drainage regions: Limpopo; Olifants; Vaal; Orange; Breede and Crocodile. Sites were located at various positions along the longitudinal profile of these rivers.

Data exploration prior to analysis followed the steps recommended by Zuur et al. (2010). This involved familiarisation with the data, assessment of multicollinearity, removal of outliers and, where appropriate, identification of suitable data transformations (log transformation of electrical conductivity and turbidity data, and square root transformation of ASPT data). Thereafter, the correlation of SASS metrics with turbidity data as well as pH, temperature, dissolved oxygen and electrical conductivity levels was assessed using multiple linear regression. The relative importance of each parameter used in the regression model was assessed using the Lindeman, Merenda and Gold (LMG) method proposed by Lindeman et al. (1980) and implemented by Grömping (2006). The method decomposes the regression R^2 into non-negative unordered contributions by regressors that sum to the total R^2, and so provides a measure of the importance of each regressor in the regression model. The robustness of these importance scores was assessed following bootstrap resampling.

The above analysis was then repeated using a subset of data (51 records) taken from only reference sites. Within the Rivers Database some entries have been identified by SASS practitioners as being from reference sites. While there is no definition of 'reference' in the database this was interpreted as indicating a site unimpacted by anthropogenic activities. The rationale behind this approach was to assess the relationship between SASS metrics and turbidity while minimising the extent of potentially confounding responses that may be linked to human impacts.

The same approach was used to assess the relationship between turbidity and the biotope-specific (or habitat-specific) SASS metric results at the various sites. The aim of this approach was to determine whether habitat-specific responses to turbidity might exist.

Data analysis was undertaken using R 3.0.2 (R Core Team 2013). Data access used the package RODBC (Ripley and Lapsley, 2013); assessment of regressor importance used the package relaimpo (Grömping, 2006), and production of graphics utilised ggplot2 (Wickham 2009) and gridExtra (Auguie, 2012).

RESULTS

Initial data exploration suggested some correlation might exist between conductivity and turbidity levels, leading to the concern that any responses apparently due to turbidity might in reality be a reflection of changes in conductivity, and vice versa. However, assessment of the variance inflation factor scores of environmental data found all of these to be below 1.5, indicating that multicollinearity levels were low enough to proceed with the analysis using all environmental data (Zuur et al., 2010).

Plots of the SASS metrics ASPT, SASS Score and NOT against turbidity are presented in Fig. 1. All three metrics were found to be significantly correlated with turbidity (ASPT R^2=0.10 p<0.001, SASS Score R^2=0.12 p<0.001, NOT

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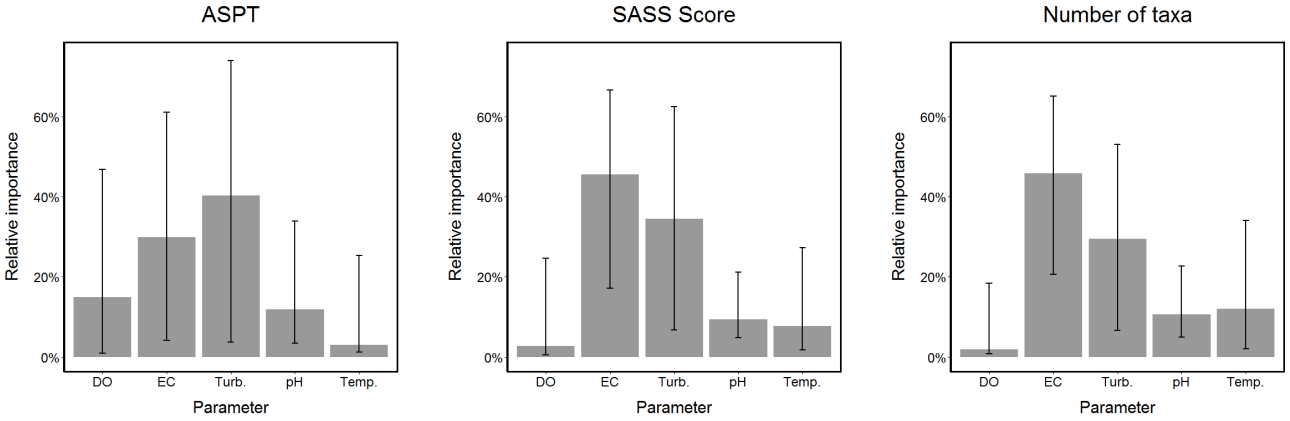

Figure 2

Relative importance of various physicochemical parameters in contributing to regression model R^2. Error bars show 95% confidence limits as derived by bootstrap resampling. Parameters are dissolved oxygen (DO), electrical conductivity (EC), turbidity (Turb.), pH and temperature (Temp.)

R^2=0.10 p<0.001), and, in all cases, the relationship was negative, such that increased levels of turbidity were associated with lowered SASS metrics. Nevertheless, inspection of the plots in Fig. 1 reveals that variation owing to factors other than turbidity is relatively high.

The regression model for ASPT found that the five physicochemical parameters assessed were able to account for 19% of the variation in ASPT score. Of the variation explained, 40% could be linked to turbidity, which was found to have greater influence over the ASPT score than any other measured parameter (Fig. 2). Although turbidity had the highest relative importance score, confidence intervals determined using bootstrap resampling around all scores are wide, and suggest that distinguishing statistically between many of the parameters might not be possible. However, it has been observed in simulations that confidence limits devised in the manner applied here can be somewhat high (Grömping, 2007).

In contrast, turbidity was not the major driver of changes in SASS or NOT scores, as conductivity levels were found to account for more of the variation in these metrics (Fig. 2). However, changes in turbidity were still a major correlate of changes in SASS and NOT scores. Combined, the two parameters accounted for 80% (SASS Score) and 75% (NOT) of the variation in the regression model. Interestingly, the multivariate regression models for SASS Score and NOT accounted for more of the observed variation in these metrics than was the case with the ASPT model, accounting for 27% and 35% of variation, respectively.

When SASS metrics from the three sampled habitats (vegetation; stones; and gravel/sand/mud) were assessed separately, the trends observed largely approximated those described above. However, the response of ASPT scores to turbidity changes across the habitats was an exception to this. Turbidity had an elevated contribution to changing ASPT scores in samples from vegetation (63%), while the effect of turbidity was somewhat reduced in samples from stone (29%), and greatly reduced in samples from gravel/sand/mud (7%).

Reassessment of changes in SASS metrics using data from reference sites alone was considerably hampered by loss of statistical power as a consequence of using a smaller dataset (51 samples versus 157 for the full dataset) for the analysis. Although the models generated were for the most part not statistically significant at p≤0.05, one observed trend was a decrease in the importance of turbidity in changing scores of all three SASS metrics. The reverse was true for the importance of pH and dissolved oxygen. Inspection of the data revealed that the higher levels of turbidity encountered in the full dataset were reduced in the reference dataset, and this may contribute to the results observed. However, the dataset was too small for firm conclusions to be drawn.

DISCUSSION

Macroinvertebrates show longitudinal zonation with assemblages from upland rivers being distinct from those of lowland rivers (Dallas, 2004). Those macroinvertebrates occupying lowland sand-dominated rivers tend to be hardy, adaptable species with the consequence that SASS metrics are generally lower at these sites (Dickens and Graham, 2002; Dallas, 2007a). With the tendency of turbidity to increase down the length of a river it is perhaps not unexpected that SASS data from the Rivers Database were negatively correlated with concurrently measured turbidity values. All of the SASS metrics were also negatively correlated with concurrently measured electrical conductivity.

Analysing SASS metrics separately by biotope or habitat yielded much the same results as analysing SASS metrics of pooled or combined habitats. The one exception was the change in response of ASPT across different habitats, with turbidity greatly affecting the ASPT of vegetation habitat sampled, while having little effect on the ASPT of gravel/sand/mud habitat. A possible cause of this trend is the relative intolerance of taxa associated with vegetation (compared with taxa associated with gravel/sand/mud) to the effects of suspended sediments as measured by turbidity. The assessment of SASS metrics response to turbidity at only reference sites revealed little, although this approach was limited by the few data points that were available. Similarly, Dallas (2007b), using the presence/absence of macroinvertebrates sampled using SASS methodology, found that turbidity was not a significant environmental predictor of *a priori* defined reference sites in Mpumalanga; however, percentage deposited mud in the stones biotope was. Subsequently, Kefford et al. (2010) have suggested that deposited sediments appear to have a greater negative biological effect compared to the effects of suspended sediment. This suggests that using SASS metrics and turbidity data together as

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a method of monitoring the effects of suspended sediment on macroinvertebrates may not be appropriate. However, in the case of the Rivers Database, 79% of the reference site turbidity data was lower than 10 NTU, with only one turbidity value above 50 NTU, suggesting that effects of suspended sediment on organisms at most sites might have been negligible anyway. For a proper assessment of the potential correlation between SASS and turbidity, sites with higher levels of turbidity – but not other stressors – would be required.

One of the few field studies undertaken in South Africa investigating macroinvertebrate responses to suspended sediment exposure, Ractliffe (1991), showed that macroinvertebrate community structure was altered by prolonged exposure to high concentrations of TSS. In that study, macroinvertebrates were sampled from sites along the Lourens River, in the southern Western Cape Province, where the only abiotic change was increased magnitude of exposure, for longer periods, to suspended sediments at downstream sites. Although the initial spate after heavy rain would result in TSS concentrations exceeding 200 mg/ℓ at all sites, after 24 h there had been a rapid decrease in TSS at the upstream site to 100 mg/ℓ, and then to 25 mg/ℓ after 48 h. In contrast, TSS at downstream sites remained high (in excess of 100 mg/ℓ) for up to 5 days. The distance between the uppermost site and lowermost was only 3 km, yet there was a loss or drastic reduction in macroinvertebrate species characteristic of mountain streams and upper river zones. The loss of Ephemeroptera species was particularly noticeable. In that study, the five taxa found to contribute most to the dissimilarity between the upstream and downstream sites were, in order of percentage dissimilarity contributed: the Teloganodid mayfly *Lithogloea harrisoni*; Chironomidae morphospecies G; Tricopteran *Athripsodes* sp.; Baetidae juveniles (were not identified further); and the Coleopteran Elmidae morphospecies C. The Ractliffe (1991) study suggests that the biological responses of macroinvertebrates to suspended sediment exposure may need to be determined to morphospecies, or at least genus level, in order to discern impacts. This is in contrast to the SASS metrics reported on here, which identify organisms to a family level only.

A number of international studies have investigated spatial patterns of macroinvertebrate assemblages, and the use of structural and functional metrics, for detecting the impacts of fine sediment exposure. Wagenhoff et al. (2012) exposed macroinvertebrates in experimental mesocosms to varying gradients of settled sediment depth and percentage cover over 21 days. Results indicated changes in macroinvertebrate assemblage (in which taxa were identified to genus level) with increasing settled sediment exposure. Furthermore, both structural taxon-based metrics (e.g. richness and density of all taxa and of Ephemeroptera, Plecoptera and Trichoptera taxa – EPT), and functional trait-based metrics (e.g. deposit-feeder; predator; burrower; clinger; grazer; filter-feeder; lays eggs at water surface; spherical body shape; and number of reproductive cycles per individual, etc.) responded definitively to settled sediment exposure. In a recent field-based assessment of the impacts of fine sediments on macroinvertebrates in a Spanish river, Buendia et al. (2013) also showed that most taxon-based metrics (with the exception of % EPT and Pielou's evenness diversity index) and selected trait-based metrics were capable of detecting ecological responses to sedimentation, making the point that trait-based metrics are useful in understanding the mechanisms responsible for the observed patterns in macroinvertebrate abundance and distribution.

CONCLUSIONS

There were significant negative correlations between concurrently measured turbidity and SASS metrics archived in the Rivers Database, although variance in the fitted models remained high. Consequently, SASS can be considered to be a reliable, if rather crude, indicator of the negative biological implications of excessive instream turbidity. Cited research suggests that the high variance may be a consequence of the SASS metrics having less sensitivity to the biological effects of turbidity compared with certain trait and taxon-based metrics which better reflect the mechanism of action of turbidity. Cited literature also suggests that turbidity may be less influential that other measures of instream sedimentation (e.g. settled sediment concentrations). Future investigations of macroinvertebrate responses to excessive sediment exposure in South African rivers should investigate the taxon and trait-based metrics discussed here and compare these with instream sediment measures such as total suspended solids and settled sediment concentrations in an attempt to more accurately define the relationship between macroinvertebrate response and excessive sediment exposure.

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