A computer based reappraisal of bioindicator zone preferences and weights within the Saprobic Index using data from river quality surveys in Slovenia

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Abstract

We use data from biological river quality surveys in Slovenia in the period of 1990-1995 to derive bioindicator saprobic values and weights which mirror the ones assigned by ecological experts. This study is motivated by a computer-based reappraisal of the Biological Monitoring Working Party scores using data from the 1990 river quality survey of England and Wales, where the revised scores substantially differed from the original in several cases. We discuss the revised bioindicator saprobic values and weights where significant differences appear from the original ones. The approach adopted here can also suggest saprobic values and weights for taxa that are currently not used as bioindicators.

1 Introduction

It is well known that the physical and chemical properties give a limited picture of water quality at a particular point in time, while the biota (living organisms) act as continuous monitors of water quality over a period of time (Cairns et al. 1968). This has increased the importance of biological methods for monitoring water quality (De Pauw and Hawkes 1993). Since Kolkwitz and Marsson (1902), who first proposed the use of biota as a

means of monitoring the quality of natural waters, many different methods for mapping biological data to discrete quality classes or continuous scales have been developed (for overviews, see Friedrich et al. 1992, De Pauw and Hawkes 1993, Grbović 1994). Most of these approaches use indicator organisms (bioindicators), which have well known ecological requirements and are selected for their sensitivity / tolerance to various kinds of pollution. Given a biological sample, information on the presence and density of all indicator organisms present in the sample is usually combined to derive a biological index that reflects the quality of the water at the site where the sample was taken.

An example of a well known biological index is the Saprobic Index (Pantle and Buck 1955), based on the Saprobic System of Kolkwitz and Marsson (1902), which is used in many countries of Central Europe, including Germany and Slovenia. A bioindicator is assigned a saprobic value SV, which specifies the water quality class where the bioindicator is most frequently found, and a weight W, which depends on how spread across different quality classes the presence of the bioindicator is (a single organism can be present in waters of different quality). The frequency of occurrence h (number of organisms found in the sample) of the bioindicator is also taken into account. The Saprobic Index SI at a given sampling point is calculated as

$$SI = \frac{\sum_{i=1}^{n} SV_i W_i h_i}{\sum_{i=1}^{n} W_i h_i}$$

where i ranges over all bioindicators present in the sample.

Bioindicators can be identified at different taxonomical levels, e.g., at the species level or the family level. A family, a species or any other taxonomical group can be referred to as a taxon (plural taxa). In the Saprobic System, bioindicators are identified at the species level, which is more demanding in terms of sample processing effort, but also gives a more precise picture of the water quality. Family level identification is used in the Biological Monitoring Working Party Score (ISO-BMWP 1979), abbreviated as BMWP, and its derivative Average Score Per Taxon (ASPT). Both are in use in the United Kingdom. A single number (score), is assigned to each bioindicator. Only the presence/absence of bioindicators is taken into account. The scores of all bioindicators present in the sample are summed to yield the BMWP score and this is divided by the number of bioindicators present to obtain the ASPT. Unlike the Saprobic Index, which includes both plant and animal taxa, the BMWP score relies on animals only, more specifically macrobenthic invertebrates, i.e., invertebrates that live in the river bed.

The main problem with the biological indices described above is their subjectivity (Walley 1993). Namely, the assignment of saprobic values, weights, and BMWP scores, to individual bioindicators was done by expert biologists and ecologists or committees thereof. The numbers assigned are

based on the experts' knowledge about the ecological requirements of the bioindicator taxa, which is not always complete. The assigned bioindicator values are thus often inappropriate, as suggested by a recent reappraisal of the BMWP scores using data acquired through biological monitoring (Walley and Hawkes 1996).

In this paper we apply the idea of using field data to revise bioindicator values assigned by experts to the Saprobic Index method (Pantle and Buck 1955). Data from biological river quality surveys in Slovenia in the period of 1990-1995 are used. Section 2 describes the field data, Section 3 the reappraisal methodology and Section 4 the results of the reappraisal. Section 5 concludes with a discussion and some directions for further work.

2 The field data

Field data were provided by the Hydrometeorological Institute of Slovenia (Hidrometereološki Zavod Republike Slovenije, abbreviated as HMZ) that performs water quality monitoring for most Slovenian rivers and maintains a database of water quality samples. The data provided by HMZ cover a six year period, from 1990 to 1995. Biological samples are taken twice a year, once in summer and once in winter, while physical and chemical analyses are performed several times a year for each sampling site. The physical and chemical samples include the measured values of fifty different parameters, which include for example dissolved oxygen and hardness, while the biological samples include a list of all taxa present at the sampling site and their density. The frequency of occurrence (density) of each present taxon is recorded at three different qualitative levels, where 1 means the taxon occurs incidentally, 3-frequently, and 5-abundantly. Biological samples include the corresponding Saprobic Index value and the corresponding quality class as determined by the index. In our analysis, we used only the biological samples, 1106 of them.

Slovenian water authorities use the Saprobic Index method, as introduced by Pantle and Buck (1955) and modified by Zelinka and Marvan (1961), to map biological data to a continuous water quality scale. The Saprobic Index derived from a given water sample is a single real number between one and four that reflects the quality of the water. For presentation purposes, the Saprobic Index (SI) is mapped into a discrete quality scale of four basic classes and three intermediate classes, i.e., seven discrete classes: 1, 1-2, 2, 2-3, 3, 3-4, and 4. SI values between 1 and 1.5 are mapped to class 1, > 1.5 and ≤ 1.8 to class 1-2, > 1.8 and ≤ 2.3 to class 2, > 2.3 and ≤ 2.7 to class 2-3, > 2.7 and ≤ 3.2 to class 3, > 3.2 and ≤ 3.5 to class 3-4, and > 3.5 and ≤ 4 to class 4. Of the 1106 samples available, 55 samples are of class 1, 286 of class 1-2, 547 of class 2, 150 of class 2-3, 58 of class 3, 7 of class 3-4, and 3 of class 4.

Class 1 corresponds to clean waters, while class 4 corresponds to heavily polluted waters. Class 1-2 waters are designated as mildly, class 2 waters as moderately, and class 2-3 waters as critically polluted. The four basic classes correspond to the legislation defined classes, but are somewhat different, as the latter rely mainly on chemical properties.

3 The reappraisal

Our analysis assumes that the original Saprobic Values (SVs) assigned to the taxa within the Saprobic System provide a fair first estimate of their 'true' sensitivities to pollution, and that the Saprobic Index(SI), being the weighted average of several such SVs, provides the best available estimate of the site's pollutional state. This crucial assumption was also made by Walley and Hawkes (1996) for reapprising BMWP scores. If all existing SVs are a true reflection of the families' sensitivities, there should be no difference between the original SVs and the ones derived during the reappraisal. If they are not, then differences will result which indicate the direction and magnitude of any necessary changes. However, since this will also mean that the SIs on which the analysis were less reliable than originally thought, the derived SVs will only be indicative of the 'true' SVs.

The mathematics of the analysis is based on elementary notions from probability and information theory. For each taxon T analyzed, the probabilities P(T/C) are calculated for each class C, where P(T/C) is the conditional probability of taxon T being present in a given sample of quality class C. These probabilities are estimated from the field data available and are the basis for calculating the revised SVs and the corresponding weights.

It is these conditional probabilities that tell us which quality class a taxon indicates, and not the conditional probabilities P(C/T). The later are namely heavily influenced by the prior probabilities of the individual classes, which are highly uneven. Consider for example the taxon *Sphaerotilus natans*, which is present in 457 of the 1106 samples. Two graphs, depicting P(C/T) and P(T/C) for this taxon are given in Figure 1. While almost half of the occurrences of the taxon are in class 2, this taxon is not an indicator of class 2: P(T/C) monotonically increases with C and the taxon is an indicator of low quality water. This is consistent with the current use of the taxon within the Saprobic System (SV=3.6, W=3).

For a given taxon, the probabilities P(T/C) are first normalized to p(T/C), where the sum over all C of p(T/C) is 1. The revised SV for the taxon is then calculated as RSV = 1*p(T/1)+1.65*p(T/1-2)+2*p(T/2) +2.5*p(T/2-3) +3*p(T/3)+3.35*p(T/3-4)+4*p(T/4) The revised W for the taxon is calculated as RW=1+4*(log 7 - E)/log 7, where E is the entropy of the distribution p(T/C) (over the 7 possible values of C).

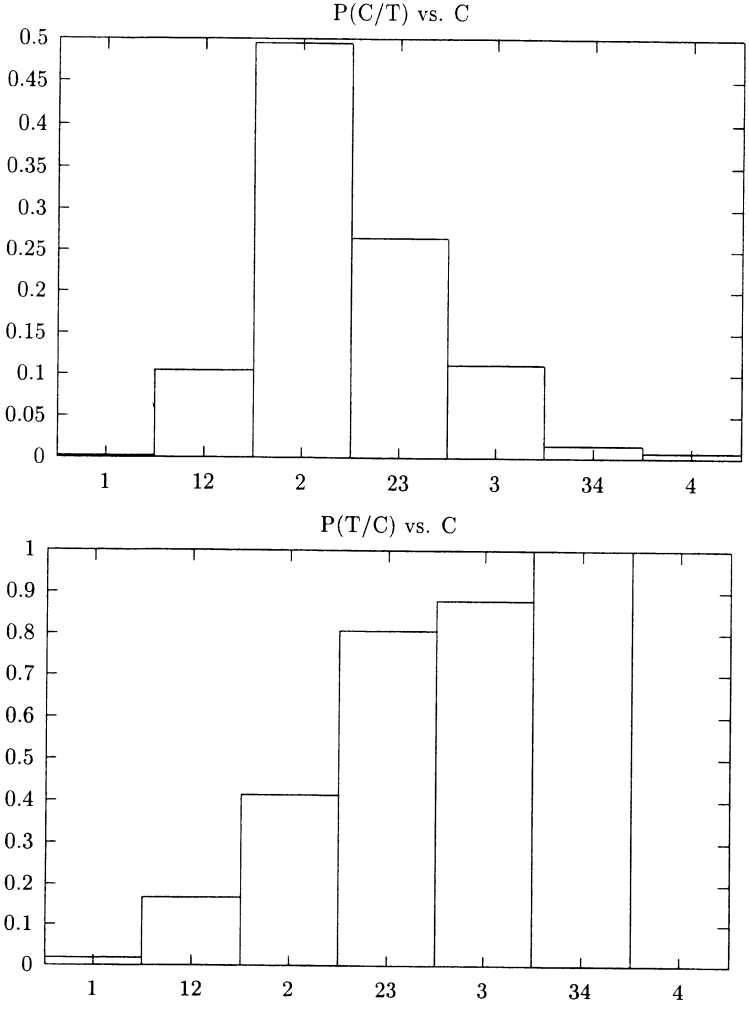


Figure 1: The conditional probabilities P(C/T) and P(T/C) for the taxon *Sphaerotilus natans*, estimated from field data.

This mimics the procedure by which experts assign SVs to bioindicators: typically 10 points are divided between the 4 main classes and the SV is calculated as a weighted average 1*p1+2*p2+3*p3+4*p4, where pi is the number of points assigned to class i. In our case, 7 classes are used instead of four because of consistency with presentations used by experts and because a finer grained picture of sensitivity to pollution is provided.

The values for the revised SVs and Ws are within the ranges 1 to 4, and 1 to 5, respectively, same as for the original SVs and Ws. Noninteger values for W are possible. W will have value 1 if a taxon is uniformly distributed across all quality classes and 5 if a taxon appears in one quality class only.

Table 1: The 20 taxa with greatest differences between original and revised SVs, their original and revised SVs, original and revised Ws, and the number of samples in which the taxa were present.

Taxon	O SV	R SV	O W	R W	Smpls
Anabaena constricta	3.8	1.99	4	2.8	18
Tabellaria fenestrata	1.0	2.23	5	2.8	13
Siphlonurus sp.	1.6	2.77	2	2.2	46
Stauroneis sp.	1.4	2.56	3	2.8	19
Cosmarium sp.	1.8	2.94	2	1.4	150
Fragilaria crotonensis	1.4	2.51	2	1.7	91
Selenastrum sp.	1.9	2.99	2	2.5	23
Dactylococcopsis rhaphidioides	1.2	2.29	4	2.5	19
Pinnularia sp.	1.2	2.28	4	3.2	12
Cocconeis sp.	1.6	2.6	2	1.4	225
Planorbis carinatus	1.5	2.43	3	2.3	10
Oligochaeta	2.9	1.99	2	1.8	72
Closterium lunula	1.3	2.13	4	2.3	28
Pleurococcus vulgaris	1.6	2.41	2	2.4	19
Cymbella prostrata	1.8	2.6	3	2.0	76
Habrophlebia lauta	1.5	2.29	3	2.2	18
Oscillatoria limosa	3.1	2.32	2	2.0	68
Surirela ovata	1.6	2.38	2	1.8	370
Chironomidae, green	1.7	2.46	1	1.1	567
Oedogonium sp.	1.4	2.16	3	2.0	322

4 Results

In the 1106 samples, roughly 850 different taxa appear. Of these, more than 400 taxa appear in at least 10 samples. There are 330 taxa that have been assigned SVs and Ws by biological experts and appear in at least 10 samples. The difference between the original SVs assigned by experts and the revised SVs exceeds 0.5 only for 65 of the 330 taxa. The 20 taxa with the greatest differences between the original and revised SVs are listed in Table 1, sorted by descending difference of SVs (first taxon has the greatest difference between original and revised SV).

Consider for example the taxon *Oedogonium sp.*, present in 322 of the 1106 samples. The original SV is 1.4, which makes it an indicator of clean waters (class 1). The revised SV is however 2.2, which makes it an indicator of moderately polluted waters. The weight is decreased from the original value of 3 to 2, as the taxon appears in waters of class 1 to 3 (see Figure 2).

Of the 20 taxa listed in Table 1, only 3 are upgraded, i.e., have lower revised SVs than their original ones: *Anabaena constricta*, *Oligochaeta*, and *Oscillatoria limosa*. The remaining 17 taxa are all downgraded, i.e., have

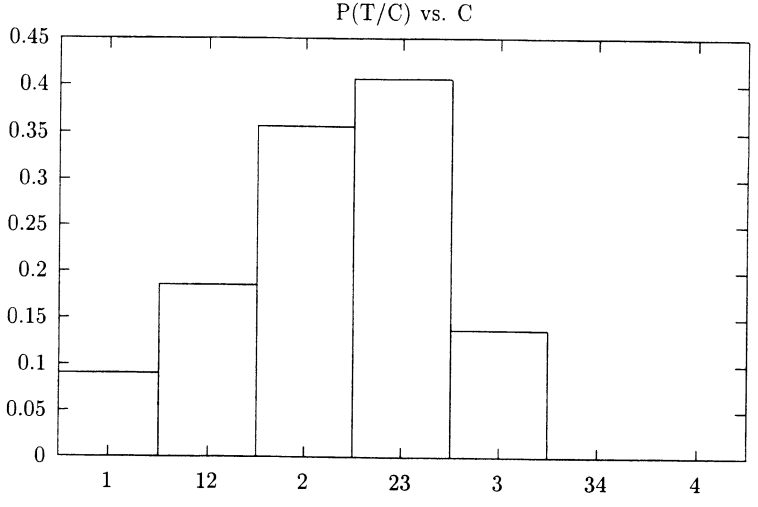


Figure 2: The conditional probabilities P(T/C) for the taxon *Oedogonium sp.*, estimated from field data.

higher revised SVs than their original ones. *Tabellaria fenestrata* is the most severely degraded one: while it had been considered a perfect indicator (W=5) of clean waters (SV=1.0), it turns out to be only a moderately good indicator (W=2.8) of moderately polluted waters (SV=2.2).

The approach we have adopted can also suggest saprobic values and weights for taxa that are currently not used as bioindicators. For example, there are three taxa that appear in at least 50 samples, are currently not used as bioindicators, and have a suggested W of at least 2.5. These are *Limoniidae* (SV=1.4, W=2.8, present in 97 samples), *Sadleriana fluminensis* (SV=1.5, W=3.0, present in 123 samples), and *Polycelis sp.* (SV=1.7, W=2.7, present in 75 samples). The conditional probabilities P(T/C) over the 7 classes for the three taxa are given in Figure 3. The Slovenian water quality expert (J. Grbović) notes that *Sadleriana fluminensis* would make an especially good bioindicator, as it is relatively immobile, i.e. not moved by drift.

5 Conclusions and discussion

We have used field data to reapprise the Saprobic Values and Weights assigned to bioindicators within the Saprobic System, as used to classify water quality samples in Slovenia. Over one thousand samples collected over a period of six years were used. Although we did not follow the same procedure as Walley and Hawkes (1996), who reapprised BMWP scores, we have applied the same basic principle. That is, we used the existing Saprobic

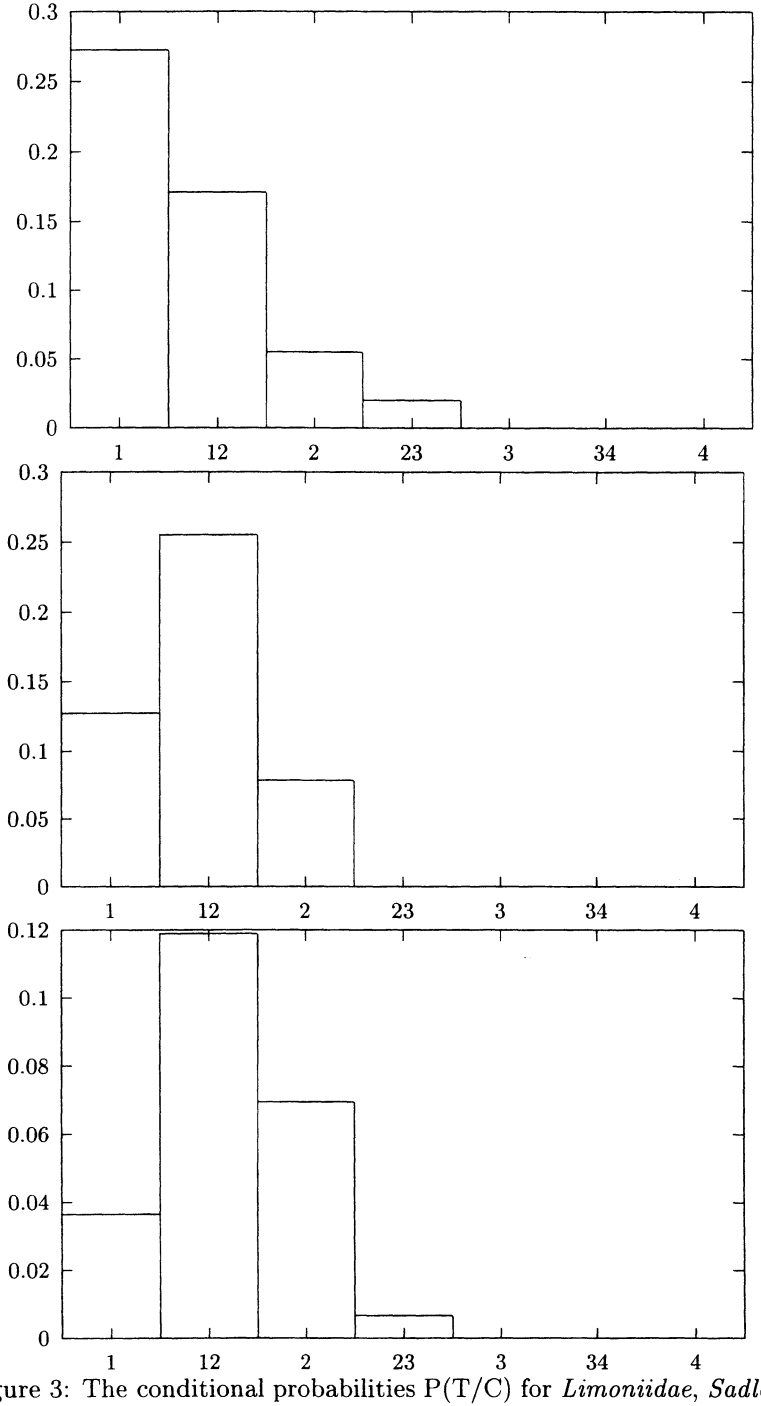


Figure 3: The conditional probabilities P(T/C) for *Limoniidae*, *Sadleriana fluminensis* and *Polycelis sp.* (top to bottom).

Values of the taxa to produce the Saprobic Indices for the samples, and then used these to reappraise the original Saprobic Values. This procedure is admissible, as the samples have a reasonable number of taxa in them.

The results indicate that for many taxa the real ecological requirements and sensitivity to pollutants significantly differ from the ones perceived by ecological experts. More detailed studies of such taxa have to be undertaken and their SVs and Ws revised if they are to remain in use as bioindicators. Machine learning methods can be used to automate the extraction of ecological requirements for selected taxa from field data (Džeroski and Grbović 1995). This is a promising direction for further work.

Our study has a number of limitations. First, it should be taken into account that very few samples were available of low water quality (Slovenia's waters are relatively clean). This might yield unreliable estimates of the conditional probabilities with respect to classes 3-4 and 4. Second, we have completely disregarded different types of sites. Walley and Hawkes (1996) consider three types of sites: riffles, pools and mixed. Slovenia's rivers are mainly torrential streams and most sampling sites are actually riffle sites, but more careful consideration should be given to justifying such assumptions. Finally, one should be careful when considering the revised SVs and Ws when the revisions are based on relatively small numbers of samples.

Let us finally mention that the Saprobic Valency diagrams (graphs depicting the P(T/C) distributions) for taxa that are well known in both the BMWP and the Saprobic Systems look very similar. Also, preliminary comparisons indicate that the computer-based reappraisals bring the two systems closer together. A more detailed comparison of the two systems in their original and revised forms will be the topic of further study.

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