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# Balancing effort and benefit – how taxonomic and quantitative resolution affect the ecological assessment of pesticide effects

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**Abstract**

Biological indices aim to reflect the ecological quality of streams based on the community´s species or trait composition. Accordingly, the capability to predict the ecological quality depends on (i) the knowledge on the association of taxa or traits with stressors and (ii) the taxonomic and quantitative resolution of taxa. Generally speaking, a higher resolution is associated with a better linkage between environmental condition and biological response but also with higher efforts and costs. So far it is unknown how the taxonomic and quantitative resolution affect the ecological quality assessment of streams related to pesticide effects when applying the invertebrate-based indicator $SPEAR_{pesticides}$. We investigated the ecological quality of 101 streams considering four taxonomic levels (species, genus, family, order) and three quantitative resolutions (abundance, three abundance classes, and presence-absence). In a multiple linear regression analysis between 13 investigated stressors and $SPEAR_{pesticides}$, the full models' explained variance remained fairly constant with decreasing taxonomic and quantitative resolution. As expected, the highest association between pesticide pressure and $SPEAR_{pesticides}$ was reached at a species/abundance resolution yielding an $R^2$ of 0.43. In contrast, the lowest quantitative resolution of order level combined with presence-absence information revealed an explained variance of 0.28 $R^2$. We suggest the family/abundance class resolution ($R^2$ = 0.38) as the best trade-off between effort and accuracy for large-scale monitoring. Due to a comparable linear regression at family/abundance class resolution, the assigned ecological quality classes were largely congruent (69%) to species/abundance resolution. We conclude that the ecological quality assessment with $SPEAR_{pesticides}$ at family/abundance class resolution can be used to link pesticide contamination and invertebrate community structure with less taxonomic expertise and less quantification effort.

## Introduction

The ecological status of streams can be determined by applying biological indices. These indices use the community's taxa or trait composition to assess the ecological quality of streams. Indices such as the %EPT (Lenat, 1988), Saprobic Index (Kolkwitz R. and Marsson M., 1909) and $SPEAR_{pesticides}$ (Liess and Ohe, 2005) aim to reflect the general degradation, oxygen deficiency, or pesticide contamination of streams. Species have specific ecological and environmental requirements but also share ecological niches, increasingly so when comparing taxonomic levels above the genus and family levels. Accordingly, with increasing taxonomic resolution, the taxa composition can be linked more accurately to environmental conditions. Similarly, increasing quantitative resolution of sampling, meaning the counting of individuals, strengthens the association between community expression and environmental conditions. In this trade-off between effort and accuracy, some countries use the taxonomic level of family (e.g. Spain: Alba-Tercedor, J and Sánchez-Ortega, A (1988); USA: Barbour et al. (1999); Australia: Smith et al. (1999); UK: Environment Agency (2008)). Instead, other countries apply species level for determining aquatic indices (e.g. USA, Germany, the Netherlands, Slovakia, and South Korea; Buss et al. (2015)). However, the strength of the relationship between environmental factors and biological indicators also depends on the accuracy of the available autecological information on the taxa investigated.

The Rhithron Feeding Type Index RETI (Schweder, 1992) and the SPEAR$_{pesticides}$ index (Liess and Ohe, 2005) , for example, contain taxonomic information for species, genus, family, and order level, whereas the Saprobic Index is mainly based on species level information with less information at genus level and almost no information at family or order level. Accordingly, Schmidt-Kloiber et al. (2004) revealed that the AQUEM Assessment software (ASS, 2000) is not applicable at genus and family level, since some indices like the Saprobic Index do not have sufficient information available at lower taxonomic levels. They found that when lowering taxonomic resolution to genus level, already half of the sites investigated were assigned a divergent ecological quality class. Regarding the trade-off between effort and accuracy for a lower quantitative resolution, Buchner et al. (2019) analyzed how presence-absence resolution affects the accuracy of ecological class assignment for biological indices. The Saprobic Index showed with a mean Spearman´s ρ of 0.93 a strong significant correlation between abundance and presence-absence data. For the General Degradation Metrics (GDM from ASS 2002), 75% of the ecological quality classes were identical with abundance resolution (Buchner et al., 2019). Accordingly, a higher taxonomic and quantitative resolution of invertebrate monitoring improves the ecological quality assessment with biological indices that involve both abundance and taxonomy.

Our aim was to identify the optimum trade-off between effort and accuracy when lowering taxonomic and quantitative resolution with $SPEAR_{pesticides.}$ For this analysis, we evaluated an extensive Germany-wide data set comprising relevant environmental factors including high resolution sampling of pesticides and high resolution sampling and determination of invertebrates. In detail, we (i) assessed the specificity of $SPEAR_{pesticides}$ to indicate pesticide pressure among multiple stressors when reducing taxonomic and quantitative resolution, (ii) evaluated the indication power under reduced resolution, (iii) investigated how ecological quality classification is impacted, and (iv) derived implications for pesticide effect monitoring.

## 2 Material and methods

### 2.1 Sampling sites

The data analyzed in this study was collected and presented by Liess et al. (2021). The macroinvertebrates and pesticide concentrations were sampled in two field campaigns from April to July in 2018 and 2019 in a Germany-wide monitoring study. This study provides information on 101 sampling sites with a varying degree of agricultural use (0 - 100%) in the hydrological catchment (n = 41 with less than 10 km²; n = 60 with 10 - 30 km² ), covering 13 different stream types (EU Commision, 2000); see SI Liess et al. (2021)). These 101 sampling sites contained 86 agricultural (more than 20% agricultural land use in the catchment area) and 15 non-agricultural sites (less than 20% agricultural land use in the catchment area). For the 11 sites monitored in both campaigns, the indicator values and environmental factors were averaged.

### 2.2 Pesticide monitoring and analyses

Water samples (n = 320) were taken with event-driven automated samplers (MAXX TP5, Rangendingen, Germany) to capture the peak concentrations induced by significant rise of water level (5 cm, depending on stream bed, Liess et al. (1999)). After the device was activated, a mixed sample of 500 mL with 40 subsamples (every 5 minutes) was collected over a total period of 3 hours and 20 minutes (Liess et al., 2021). Additionally, streams were sampled regularly with 250 ml grab samples (n = 520) every three weeks according to WFD standards (EU Commision, 2000). 75 pesticides and 33 pesticide metabolites were selected by prioritization according to active substance-related sale quantities, under consideration of the current environmental quality standards (EQS) and the regulatory acceptable concentrations (RAC) (Wick et al., 2018) (see list of substances in SI Liess et al. (2021)). All 830 water samples were analyzed for these 108 substances via target analysis with high pressure liquid chromatograph coupled with a high-resolution tandem mass spectrometer LC-HRMS/MS without enrichment by multiple-reaction-monitoring (MRM, (Halbach et al., 2021; Reemtsma et al., 2013)).

### 2.3 Transferring measured concentrations into invertebrate toxicity

All pesticide concentrations from EDS and grab samples were converted into invertebrate toxicity by calculating Toxic Units (TU; Sprague (1970)) with the substance-related acute $LC_{50}$ value of *Daphnia magna* or *Chironomus sp.* (most sensitive organism selected per substance) (Münze et al., 2017). $LC_{50}$ values were collected from the Pesticide Property Data Base (PPDB and the US EPA ECOTOXicology knowledgebase in case of lacking *Chironomus* data) (Lewis et al., 2016). Peak exposure in streams to pesticides toxic to invertebrates was determined by the local maximum single substance insecticidal toxicity measured according to Liess et al. (2021).

### 2.4 Macroinvertebrate sampling

Macroinvertebrates were sampled after the main application of pesticides in June in 2018 and 2019 at each site (Liess et al., 2021). The macroinvertebrate sampling followed the Water Framework Directive (WFD) guideline (Meier et al., 2006) commonly used by the German federal states. At each site, a 50-meter section downstream of the monitoring site was sampled. Regarding all microhabitat types, 20 subsamples were taken with a kicking net according to their share in the stream section (at least 5%). Subsequently, macroinvertebrates were filtered, sorted, and conserved in 90% ethanol until laboratory determination. Taxa were identified to the highest possible taxonomic resolution using a binocular (Zeiss, Stereo Discovery V.20, Carl Zeiss Microscopy GmbH; Jena, Germany).

### 2.5 Calculation of the biological indicator - $SPEAR_{pesticides}$

The effects of pesticides on macroinvertebrates were quantified using the bio-indicator $SPEAR_{pesticides}$ by (Liess and Ohe, 2005). $SPEAR_{pesticides}$ provided the relative abundance of vulnerable species within a community and was normalized to indicator values under pristine conditions according to Liess et al. (2021).

Different taxonomic resolutions were considered by aggregating the taxa to the respective taxonomic level and summing up the abundances before transforming the data. For quantitative resolutions, the abundances were adjusted to presence-absence and three different abundance classes (see 2.7.1). In conclusion, the same $SPEAR_{pesticides}$ formula were applied to all taxonomic and quantitative resolutions.

$SPEAR_{pesticides}$ is calculated by using the following equation (Knillmann et al., 2018):

$$SPEAR_{pesticides} = \frac{\sum_{i=1}^{n} log10(4x_i + 1) \cdot y_i}{\sum_{i=1}^{n} log10(4x_i + 1)}$$

where *n* is the total number of taxa in a sample, $x_i$ is the abundance of taxon i (given as individuals per $m^2$), and *y* is set to 1 if taxon i is classified as “at risk” (Liess and Ohe, 2005) – i.e. vulnerable to pesticides under regular exposure events – and set to 0 otherwise.

Trait information on vulnerability is allotted to 1,581 species in the $SPEAR_{pesticides}$ database, 1,325 of which are sensitive and 256 insensitive. At the genus level, 255 taxa are assigned sensitivity information, divided into 186 sensitive and 69 insensitive. Information for 53 sensitive and 111 insensitive families is available, while at the order level only four orders are classified as sensitive (Ephemeroptera, Trichoptera, Plecoptera, Megaloptera) and 11 as insensitive. According to the results of this study, the groups Diptera Gen. sp. and Crustacea Gen. sp. were classified as not vulnerable and the order Megaloptera Gen. sp. as vulnerable.

### 2.6 Biotic and abiotic parameters

To reveal the relationships between environmental factors and ecological status, we collected biotic and abiotic parameters as described in Liess et al. (2021). Oxygen content, water level, conductivity, and water pressure were measured continuously from April to June (Liess et al., 2021). Nutrients and metals were analyzed in EDS and grab samples. Flow velocity and water level were measured every three weeks. Hydromorphological parameters were identified once according to the guidelines of the WFD. For more in-depth information regarding each method and parameter, please refer to Liess et al. (2021).

### 2.7 Data analysis

#### 2.7.1 Taxonomic and quantitative resolutions

In a first step, the taxa numbers corresponding to each taxonomic level were summed. For lower quantitative resolutions, the abundance was set to one or zero for presence-absence or grouped into three classes for abundance class resolution. The smallest class contained abundances from one to three, the middle class comprised abundances from four to 100, and the third class included abundances greater than 100. Ultimately, the same $SPEAR_{pesticides}$ equation (see chapter 2.5) was applied to all taxonomic levels of abundance, presence-absence, and abundance class resolution.

In a second step, we evaluated the differences between $SPEAR_{pesticides}$ values resulting from four taxonomic (species, genus, family, and order) and three quantitative (abundance, abundance class, and presence-absence) resolutions visually using linear correlation (see SI figure 1) and with a paired Wilcoxon-test (see SI table 1). As for other German invertebrate metrics under the WFD, the four $SPEAR_{pesticides}$ boundaries separating the five even quality classes equal Ecological Quality Ratio values of 0.8, 0.6, 0.4, and 0.2 (Environment Agency, 2008; EU Commission, 2008; Liess et al., 2021).

#### 2.7.2 Linear regressions, visualization, and ecological class assignment

The prediction quality of all resolutions was evaluated by a multiple linear regression analysis with a two-way interaction of 13 environmental variables (for the environmental variables refer to Liess et al. (2021)). The relative importance of each variable was calculated with the relaimp package (version 2.2-3) in R and given in $R^2$ (Grömping, 2006).

The effects of pesticide pressure on macroinvertebrate communities evaluated by $SPEAR_{pesticides}$ were modelled by single linear regressions for the different taxonomic and quantitative resolutions. The indication power of different levels of taxonomic and quantitative resolutions were assessed by comparing linear model $R^2$ values. The regression slopes + y-intercepts of $SPEAR_{pesticides}$ were compared.

In addition, the percentage of congruence of the assigned ecological quality classes for all lower taxonomic and quantitative resolutions compared to the species/abundance resolution was evaluated. Data was processed using the software R (version 4.0.2, R Core Team, 2020. All diagrams were generated with the "ggplot2" version 3.3.2 in R (Wickham, 2009).

#### 2.7.3 Compensation factor at order level

At the order level, for each quantitative resolution, a compensation factor was empirically derived. The compensation factor approximates the order-level $SPEAR_{pesticides}$ values to those at species/abundance resolution. The validity of the approximation is represented by a similar slope and y-intercept of the regression lines compared to species/abundance resolution as well as by a higher congruence in ecological class assignment (Fig. 2, B and C).

## 3 Results and discussion

### 3.1 Indication power (performance) of $SPEAR_{pesticides}$ using different taxonomic and quantitative resolutions

#### 3.1.1 Indicating pesticide pressure among other stressors

$SPEAR_{pesticides}$ reflects the effect of pesticide pressure on the macroinvertebrate community composition. To evaluate the specificity of the different resolutions of $SPEAR_{pesticides}$, we assessed the response of $SPEAR_{pesticides}$ to 13 environmental and anthropogenic stressors considered relevant for the benthic invertebrate community. Here, we used a multiple linear regression analysis to identify the relative importance of each of the potential stressors: pesticide pressure; deficient hydromorphology; deficient bed habitat structure; $O_2$ deficiency;

nutrient pollution by $NH_4$; $NO_2$; total phosphorus; flow velocity; metal toxicity; temperature; pH; and stream morphology stressors (Liess et al., 2021). Two of the 13 stressors included were associated with $SPEAR_{pesticides}$ at all taxonomic and quantitative resolutions investigated (Fig. 1). In the full models, the explained variance ranged from an $R^2$ of 0.55 to 0.61 for all taxonomic and quantitative resolutions, while remaining relatively independent of the resolution of $SPEAR_{pesticides}$. All full models reflected the specificity of $SPEAR_{pesticides}$ through the identified main driver pesticide pressure ($TU_{max}$), which contributed an average explained variance of 0.26 $R^2$ up to the family level. Deficient hydromorphology added an average explained variance of 0.16 $R^2$ to the full model for all resolutions. $NH_4$ was only identified as relevant by abundance class and presence-absence resolution – but at all taxonomic levels – and added an average explained variance of 0.08 $R^2$ to the full model. Deficient bed habitat structure contributed an average $R^2$ of 0.07 and was found to be relevant mainly for abundance resolution but also for the genus and family level at the two lower quantitative resolution. $O_2$ deficiency added an average $R^2$ of 0.06 to the explained variance in the full models affecting only the order-level full models' explained variance (Fig. 1). At the order level, the relevance of the main driver pesticide pressure is underestimated. However, our results indicate that the specificity of $SPEAR_{pesticides}$ toward toxic pressure decreased at lower quantitative resolution while $NH_4$ and hydromorphology explain more and toxicity less of the variance. The specificity of $SPEAR_{pesticides}$ is validated regarding the explanatory power of lower taxonomic resolutions up to the family level in terms of multiple stressors.


**Fig. 1 Overview of the multiple linear regression analysis. The relative importance of each of the five significant parameters for the different taxonomic and quantitative resolutions of SPEAR$_{pesticides}$ is specified in explained variance by $R^2$ values. Black dots indicate the full models explained variance, whereas blue and red dots reflect the positive and negative influence of each stressor contributing to the full models' explained variance. Stars next to the $R^2$ indicate the level of significance ($p < 0.05$ = *, $p < 0.01$ = **, $p < 0.001$ = ***).**

With the multiple linear regression analysis, we confirmed the specificity of SPEAR$_{pesticides}$ toward pesticide pressure at all quantitative resolutions up to the family level. In the following, we will focus on the indication power of SPEAR$_{pesticides}$ at lower taxonomic and quantitative resolution. In a single linear regression analysis between SPEAR$_{pesticides}$ and pesticide pressure, resulting $R^2$ values for all combinations of taxonomic and quantitative resolution ranged from 0.32 (order/presence-absence; Fig. 2 A) to 0.43 (species/abundance; Fig. 2 A). In general, $R^2$ values increased with increasing taxonomic and quantitative resolution, except at the genus level (Fig. 2 A). We found only a slightly decreasing explanatory power ($R^2$) up to the family level. With reducing the taxonomic resolution, the trait information basis changed. At the genus level, genus sensitivity information was only available for 11% of genus taxa of all sites, while 84% of genus taxa were linked at family level and 5% at order level. At species level, only 17% of species taxa of all sites had sensitivity information. The majority of 80% had sensitivity information at family level. Although the effect of pesticide pressure on the invertebrate community could be linked up to the order level according to the $R^2$ values, in some cases considerably deviating $SPEAR_{pesticides}$ values indicated a higher prediction uncertainty at order level.

Order level lead to an increase of most $SPEAR_{pesticides}$ values. These higher $SPEAR_{pesticides}$ values at order level are not shifted in parallel (Fig. 2 A; SI). Streams with high ecological quality deviated more than streams with lower ecological quality. Aggregating all higher taxonomic trait information at order level is not feasible for every order, as many contradictory higher trait information are combined. Some families classified as insensitive at the family level (Hydropsychidae Gen. sp., Leptociridae Gen. sp., Sericostomidea Gen. sp., Ephemerellidae Gen. sp., Leptophlebiidae Gen. sp., Nemouridae Gen. sp.) belong to the EPT group. The EPT group is classified as sensitive at order level, thus increased the $SPEAR_{pesticides}$ values. In the $SPEAR_{pesticides}$ database, 15 orders are implemented to which vulnerability information could be assigned. Four orders are categorized as sensitive and 11 as insensitive towards pesticides. To overcome the systematic shift of EPT rich streams at the order level, we derived and applied a compensation factor of 1.2 for order/abundance and 1.3 for abundance class and presence-absence resolution. This compensation factor approximated order level values to that of species/abundance resolution to enable order level prediction (Fig. 2 B; SI). Despite the compensation factor, many order-level $SPEAR_{pesticides}$ values still diverged from species-level $SPEAR_{pesticides}$ values which can be explained by reduced numbers of taxa at order level. Linearly adjusting the order-level $SPEAR_{pesticides}$ values only compensated the systematic shift but did not allow to improve the prediction quality in terms of $R^2$.

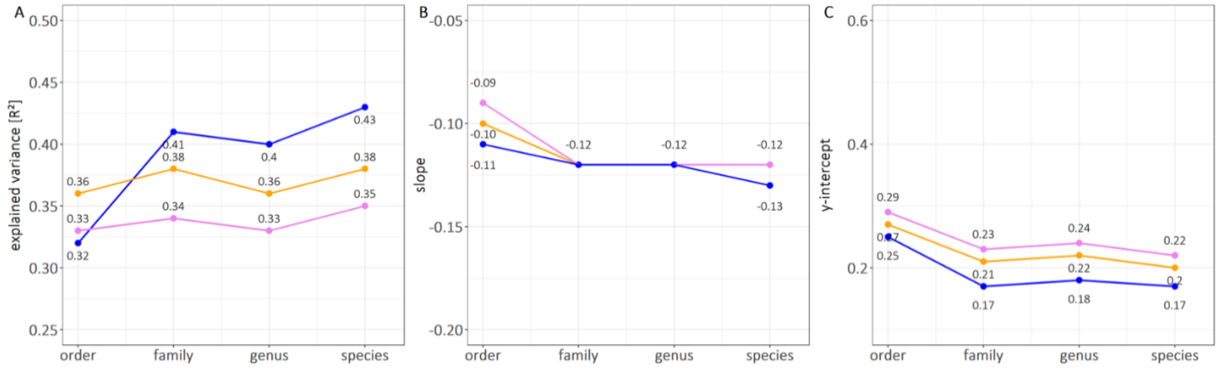


**Fig. 2 SPEAR$_{pesticides}$ as a function of maximum pesticide toxicity expressed (TU$_{max}$) for 101 sampling sites. The three figures show the (A) explanatory power of the linear regression, (B) their respective slope, and (C) y-intercept. The points for each taxonomic level were connected as each level also contains some lower taxonomic resolutions.**

### 3.1.2 Congruence and divergence between species and family SPEAR$_{pesticides}$

For most stream monitoring sites, species and family SPEAR$_{pesticides}$ values were similar. With an explained variance of $R^2 = 0.41$, family/abundance resolution associate pesticide pressure and SPEAR$_{pesticides}$ second accurately. Additionally, an identical slope and y-intercept of the linear regression at family level indicated a high congruence to species level regression SPEAR$_{pesticides}$ values (Fig. 2 B, C). This congruence can be explained by three possible reasons. Firstly, trait information in the SPEAR$_{pesticides}$ indicator at the species level is only available for one-third of our determined species, while most of the identified species are linked to family level trait information. The frequency of each taxa was not considered here. Secondly, if clear identification characteristics were absent due to damaging of individuals during the sampling process or too small to determine the taxa at species level, a lower taxonomic determination level was chosen to ensure the correct determination of the taxa. Thirdly, some trait information in the SPEAR$_{pesticides}$ database was extrapolated from higher taxonomic levels to the species level due to missing information at the species level.

These reasons are expected to explain the insignificant differences of the SPEAR$_{pesticides}$ values between “species” and “family” level at the same quantitative resolution ($p = 0.44$, Wilcoxon test, Tab. 1; SI).

Still, some family $SPEAR_{pesticides}$ values deviated from species-level $SPEAR_{pesticides}$ values. For instance, family values increased due to some insensitive taxa classified as sensitive at the family level (Rhyacophilidae Gen. sp., Phryganeidae Gen. sp., Goeridae Gen. sp., Limnephelidae Gen. sp., Hydroptilidae Gen. sp.). Decreasing family $SPEAR_{pesticides}$ values can be explained by sensitive taxa aggregated into insensitive families (Hydropsychidae Gen. sp.) at lower taxonomic resolution. Additionally, if there are many species of the same family in one stream, the $SPEAR_{pesticides}$ values at the family level decreased because the number of taxa before log-transformation decreased.

In fact, family-level or even lower taxonomic levels are known to work with some macroinvertebrate indices: the BMWP (Moolna et al., 2019), ASPT (Moolna et al., 2019), RETI (Schmidt-Kloiber, A. & Nijboer, R. C., 2004), or Anglers' Riverfly Monitoring Initiative Index (ARMI (Di Fiore and Fitch, 2016)). Taxonomic sufficiency (Ellis, 1985) is the taxonomic resolution required for a specific endpoint to predict and judge impairment or change of an ecosystem reliably. For macroinvertebrate indices, the level of adequate taxonomic resolution depends on the determination depth of invertebrates but mainly on the available taxonomic information in the index. Subsequently, depending on the invertebrate index and accordingly the integrated taxonomic information, family level is sufficient to link multiple environmental stressor to the macroinvertebrate community composition (SIGNAL, (Chessman, 1995)) or show weak to no associations between environmental conditions and community composition compared to the species level (SWAMPS, (Crowns et al., 1992)). Although species level has the highest precision in reflecting the ecological status of streams (Norris and Hawkins, 2000; Resh et al., 1995; Schmidt-Kloiber, A. & Nijboer, R. C., 2004) and is, thus, often treated as the gold standard, similar to previous studies on other indicators, our analysis for $SPEAR_{pesticides}$ showed that family/abundance resolution can be used as a surrogate for species/abundance resolution in terms of specificity and indication power.

### 3.1.3 Effects of lower quantitative resolution on prediction quality

The two lower quantitative resolutions analyzed – abundance class and presence-absence – showed slightly less powerful associations between pesticide pressure and $SPEAR_{pesticides}$ of

0.33 to 0.38 $R^2$ (Fig. 2 A) compared to abundance resolution. At lower quantitative resolutions, the association between toxic pressure and $SPEAR_{pesticides}$ was observed to be relatively independent from the taxonomic resolution. Within the same lower quantitative resolutions, the explanatory power is similar for all taxonomic levels (Fig. 2 A). By converting abundances into abundance classes or presence-absence data the relevance of the number of taxa increased while the relevance of high abundances declined with a lower quantitative resolution. The minor role of the abundance is reflected by the still high association ($R^2$) of $SPEAR_{pesticides}$ and pesticide pressure at abundance class and presence-absence resolution, even at order level (Fig. 2 A). Our correlation results at lower quantitative resolution showed for the first time that abundance class and presence-absence resolution can also provide a powerful link between pesticide exposure and $SPEAR_{pesticides.}$

**3.2 Indicating the ecological quality**

We analyzed how taxonomic and quantitative resolutions affect the assigned ecological quality in terms of $SPEAR_{pesticides}$ classes. Lower taxonomic resolution only slightly affected the ecological class assignments up to the family level. Family/abundance resolution yielded 88% congruence in ecological class assignment compared to species/abundance resolution (Fig. 3 A). At the order level, $SPEAR_{pesticides}$ provided a distinctly reduced congruence of 56% in ecological class assignment (Fig. 3; SI). In contrast, the AQUEM Assessment Software (ASS), mainly focused on species taxonomic resolution, which only reached 50% congruence at the genus level and 40% congruence at the family level in ecological classification (Schmidt-Kloiber, A. & Nijboer, R. C., 2004).

Reducing the quantitative resolution affected ecological class assignment stronger compared to a lower taxonomic resolution up to the family level. Species/abundance class resolution lead to 74% congruence compared to species/abundance resolution. Species/presence-absence resolution resulted in 65% congruence, the lowest accuracy at the species level in class assignment with $SPEAR_{pesticides}$. Hence, at lower taxonomic and quantitative resolution, a class shift of individual streams occurred. We found that a shift into a better ecological class was more likely than into a worse class (see EXCEL workbook; SI). As indicated by the Aquem

Assessment Software applied at lower taxonomic resolution (ASS: Schmidt-Kloiber, A. & Nijboer, R. C. (2004)) and its General Degradation Metrics applied with presence-absence resolution (GDM: Buchner et al. (2019)), we also observed a class shift of up to two classes but in our case only at the order level (Fig. 3; SI). We observed that class shifts mainly occurred when the species/abundance resolution $SPEAR_{pesticides}$ value is close to an ecological class boundary. Therefore, we suggest that at lower taxonomic and quantitative resolution the assigned ecological class – but also the $SPEAR_{pesticides}$ value itself – should be considered for evaluation of individual streams.

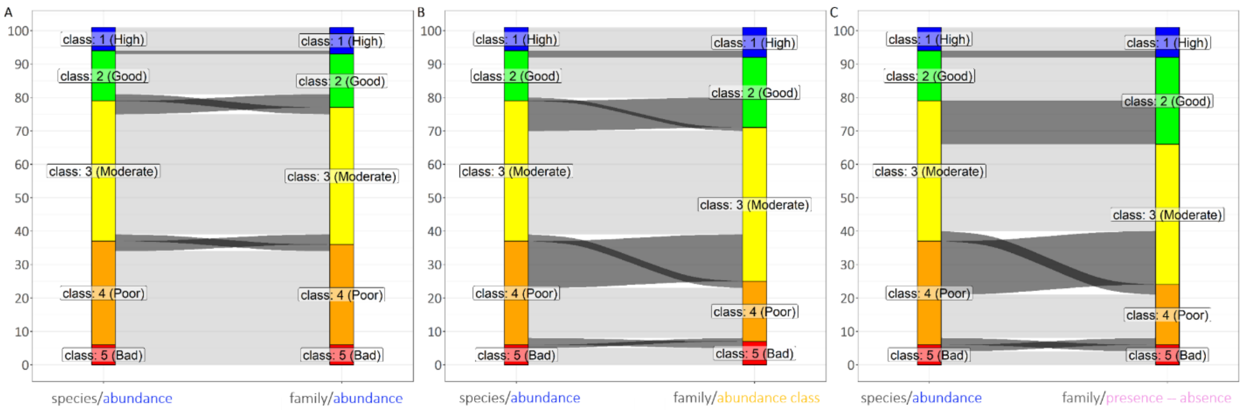


**Fig. 3 Comparison of ecological classification in terms of $SPEAR_{pesticides}$ under A) species/abundance and family/abundance resolution (88% congruence), B) species/abundance and family/abundance class resolution (69% congruence), and C) species abundance and family/presence-absence resolution (62% congruence). The ecological classes are displayed from "High" (blue) to "Bad" (red) and symbolize the ecological quality of invertebrate communities for each of the 101 streams (y-axis). The light grey horizontal bars show that the majority of streams are classified equally. The dark grey horizontal bars show streams shifting one class higher or lower due to lowering the taxonomic and quantitative resolution.**

### 3.3 Implications for pesticide effect monitoring

Large-scale monitoring implies working with multiple field personnel with different macroinvertebrate sampling skills, resulting in a higher likelihood of sampling errors that can occur when estimating macroinvertebrate abundances in the field (Metzeling et al., 2013). To avoid those sampling errors according to Giehl et al. (2014), many monitoring studies are based on presence-absence resolution, rather than abundance resolution. As an example, Australian state-wide biomonitoring has adopted the use of family/presence-absence resolution rather than species/abundance resolution (Marshall et al., 2002). Our study for $SPEAR_{pesticides}$ also revealed that abundance class resolution is a simplified approach for differently skilled field personnel and less prone to sampling errors. This lower quantitative resolution provides less accurate but still adequate indication of pesticide pressure and the related ecological status. Whereas the trade-off for presence-absence resolution is higher as the derived ecological status deviated in 35% of cases from the maximum resolution assessment and should be restricted to monitoring where the scope is to only get an impression of the analyzed invertebrate community composition. Reduced quantitative resolution requires less material for the conservation of taxa and consequently the monetary expenditure is lower (Bush et al., 2019; Marshall et al., 2006). Depending on the availability of personnel, time, and material, the respective quantitative resolution should be chosen. Accordingly, we suggest applying $SPEAR_{pesticides}$ at family/abundance class resolution as a good trade-off for large-scale monitoring. The deviating ecological classifications are minor restrictions over the gained time efficiency and ensured determination validity in stream monitoring. Classifying the sampled macroinvertebrates into abundance classes at the family level in the field also leads to lower lethal effects in the community, as the proportion of preserved sample for laboratory determination is reduced. Hence, already stressed but also intact macroinvertebrate communities are protected, benefiting from lower taxonomic and quantitative resolution. Taxonomically and quantitatively sufficient for $SPEAR_{pesticides}$ is the sampling and determination of macroinvertebrate data at family/abundance class resolution.

# Conclusion

- Family/abundance class resolution provides the best trade-off for time-efficient large scale pesticide effect monitoring and ecological stream assessment with $SPEAR_{pesticides}$. It represents a simplified but reliable approach which is also applicable for Citizen Science programs.

- The multiple stressor analysis has shown that at reduced quantitative resolution, the $SPEAR_{pesticides}$ specificity decreased slightly while NH4 also began to codetermine $SPEAR_{pesticides}$.
- The derived compensation factors at order level enabled an approximation of the order $SPEAR_{pesticides}$ values to the species level $SPEAR_{pesticides}$ values. Still, though, the indication power is reduced at order/abundance resolution.
- Also order/presence-absence resolution can associate toxic pressure to the invertebrate community composition, but reflecting the assigned ecological status only half as accurate as species/abundance resolution.

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